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PROVO UT COMPUTER AIDED MFG LAB D K ALLEN ET AL.
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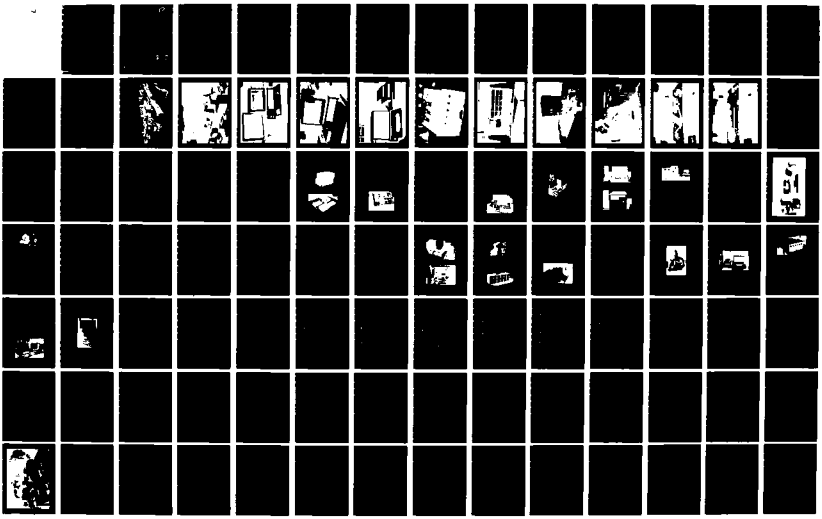

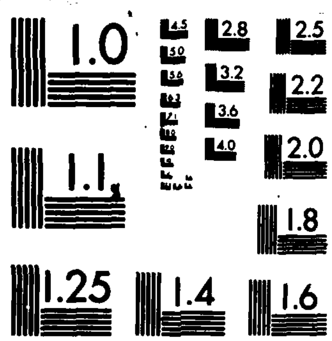

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SECOND INTERIM REPORT
For No-Cost Extension For
AFOSR Grant- AFOSR-82-0253
July 1, 1983 through Oct. 31, 1983

MANUFACTURING INFORMATION SYSTEM

Submitted to

Air Force Office of Scientific Research
Building 410, Room 223
Bolling Air Force Base
Washington, D.C. 20322 N.C.

December 22, 1983

Principal Investigators:
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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified/Unlimited	1b. RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 84-0031
6a. NAME OF PERFORMING ORGANIZATION Brigham Young University 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Air Force Office of Scientific Research
6c. ADDRESS (City, State and ZIP Code) Research Division C-37 ASB Provo, UT 84602	7b. ADDRESS (City, State and ZIP Code) Building 410 Bolling AFB Washington, D.C. 20332
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Air Force Office of Scientific Research 8b. OFFICE SYMBOL (If applicable) NE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-82-0253
8c. ADDRESS (City, State and ZIP Code) Building 410 Bolling AFB, Washington, D.C. 20332	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO.: 61102F PROJECT NO.: 2305 TASK NO.: K1 WORK UNIT NO.:
11. TITLE (Include Security Classification) Manufacturing Information System	
12. PERSONAL AUTHOR(S) D.K. Allen, P.R. Smith, M.J. Smart	
13a. TYPE OF REPORT 2nd Interim 13b. TIME COVERED FROM 83 Jly 01 TO 83 Oct31	14. DATE OF REPORT (Yr., Mo., Day) 83 Dec 22 15. PAGE COUNT 117
16. SUPPLEMENTARY NOTATION 15 month report of 28 month program	
17. COSATI CODES FIELD / GROUP / SUB. GR.	18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Manufacturing, Integrated, Information, Flexible, Distributed, System

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The size and cost of manufacturing equipment has made it extremely difficult to perform realistic modeling and simulation of the manufacturing process in university research laboratories. Likewise the size and cost factors, coupled with many uncontrolled variables of the production situation has even made it difficult to perform adequate manufacturing research in the industrial setting. Only the largest companies can afford manufacturing research laboratories; research results are often held proprietary and seldom find their way into the university classroom to aid in education and training of new manufacturing engineers.

It is the purpose for this research to continue the development of miniature prototype equipment suitable for use in an integrated CAD/CAM Laboratory. The equipment being developed is capable of actually performing production operations (e.g. drilling, milling, turning, punching, etc.) on metallic and non-metallic workpieces.

The integrated CAD/CAM Mini-Lab is integrating high resolution, computer graphics,
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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☒ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL Alan H. Rosenstein	22b. TELEPHONE NUMBER (Include Area Code) (202) 767-4931 22c. OFFICE SYMBOL NE

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parametric design, parametric N/C parts programmings, CNC machine control, automated storage and retrieval, with robotics materials handling.

The availability of miniature CAD/CAM laboratory equipment will provide the basis for intensive laboratory research on manufacturing information systems.

The proposed research and development effort for the CAD/CAM Mini-Lab will be performed in three distinct phases. The first phase, lasting 28 months is devoted to prototype development and testing of the following miniature equipment (1) CNC Lathe, (2) CNC Mill, (3) CNC Turret Punch, (4) Storage and Retrieval System, (5) Micro-Robot, and (6) CNC Machine-Tool Control System. Demonstration software is also being developed for integrating CAD/CAM graphics with the CNC Machine-Tool Control System. Phase two, one year, will be used for developing production models from the prototypes created during phase one, producing multiple copies of each piece of equipment and placing this equipment in a consortium of selected educational institutions. The planned phase three will be a one-year effort to develop extensive CAD/CAM software at institutions selected during phase two, concluding with a software exchange program. Software documentation standards will be provided for each institution to insure useability, transportability, and maintainability. It is expected that a vast amount of relevant manufacturing information will be collected and procedures developed from CAD/CAM Mini-Lab which will be directly applicable to a full-sized manufacturing plant operation. It is anticipated that programs developed by the educational consortium will include expansion of parametric design and programming applications, testing and evaluation of process control algorithms, evaluation and testing of programming procedures, experimentation with CAD/CAM Data Base design, development and utilization of group technology principles, shop floor scheduling and control, communication and distributed processing, etc., etc.

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MANUFACTURING INFORMATION SYSTEM
(Phase I)

1. INTRODUCTION

1.1 BACKGROUND

This is the second technical report for research completed during the first 18 months of a 28-month effort to develop laboratory sized manufacturing equipment. The first interim report, Appendix A, was submitted 83 July 14. This current report focuses on the work completed under a three-month no-cost extension to the first technical report.

1.2 NEED

Development of a computer aided manufacturing (CAM) laboratory at Brigham Young University was undertaken in 1974 as a BYU Centennial year activity. By 1976 a building had been erected for the laboratory and a number of pieces of full sized industrial CAD/CAM equipment had been acquired through cost-sharing and educational contributions. The original intent of the CAM Laboratory was to develop a fully integrated system for linking the Applicon Computer Graphics System to a host computer PDP 11/40 Industrial Control Computer for progress planning, scheduling, and N/C programming. The control information would then be down loaded to individual machines for producing the various parts. An Eaton-Kenway Automated Storage and Retrieval System (AS/RS) was installed for parts storage. An ASEA Industrial Robot was installed for processing, inspection, and assembly.

As the work of integration started, it was soon discovered that many large problems had to be solved in linking the various pieces of equipment. For example, it was discovered that the Bendix Cordax inspection machine could not use the graphics data base for inspecting parts produced on the CNC Milling Machine. The graphics data base did not have tolerances stored for the various dimensions. Also, the graphics data base for the wire frame model did not store relationships between the various form features.

In addition to the major challenge of physically and logically inter-connecting the full-sized equipment, there was a more pressing challenge of how to teach the various graduate and undergraduate classes. The full-sized production equipment was large and expensive and it was not feasible to provide multiple work stations. Furthermore, the equipment could be dangerous to operate and it required quite large amounts of materials. In order to solve the materials problem styrofoam blocks were used for workpieces. The styrofoam was a good choice since it would readily yield in case the student had incorrectly programmed the 20 h.p. milling machine and it suddenly started moving at rapid traverse rate while the tool was still in the cut.

The concept of developing a duplicate of the regular CAM Lab but on a miniature scale is described in a memorandum dated 22 May 1979 from D.K. Allen to J. J. Kunzler. In this memorandum it was mentioned that a Tektronix 4051 Graphics Terminal had been donated along with the mini-lathe. Matching college and department funds were requested to purchase a Macsym II Process Control Computer so that interfacing it with the mini-lathe could begin. An enclosure to the memo (Appendix D of this report) describes how the CAM Mini-Lab was planned.

The Tektronix 4051 Graphics System was being used to introduce students to concepts of parametric design. With this approach a part family could be displayed, dimensions added, and the drawing automatically scaled to size. The

miniature lathe was actually designed as a camera maker's lathe but had been retrofitted with ball-screws and digital stepper motors to permit its use for numerical control applications. In April, 1979, Superior Electric Company provided a very generous discount for stepping motor controllers to be used in the Mini-Lab.

With all of the equipment in place, Mr. Charles Snead, a graduate student enrolled in the M.S. Degree Program of Computer Aided Manufacturing was asked to begin the integration process by linking the Tektronix Graphics System, Macsym Process Control Computer and miniature lathe. The result was most encouraging. He was able to incorporate parametric design with N/C Cutter-path generation to produce a family of rotational parts having 1,2,or 3 diameters.

One problem with ths system was the very slow positioning rates for the lathe. It would take nearly twenty minutes to machine a simple part. Subsequently, Mr. Steve Painter of Grady Moore Associates was asked to develop a higher speed stepper motor driver that could be used with the popular and low-cost Apple II Microcomputer instead of the more expensive Macsym II Computer. This development took nearly 18 months, with one false start, but eventually ended up with a 6-axis controller.

In order to expand the integration concept to include other equipment, the BYU Industrial Design Department was contacted in the late spring of 1981 and asked to produce mock-up equipment for use in the Mini-Lab. Professor D.K. Allen provided specifications and met with the students many times during the development phase to review and approve their work. On June 22, 1981, an open house was held in which students discussed their projects with members of the local industrial community. (Appendix E).

In the fall of 1981, Mr. Forest Blair, a student in mechanical engineering was employed to produce assembly and retail drawings for the new miniature machine tools. Mr. Paul Smith worked closely with the project for designing the miniature turret punch, automated storage and retrieval system, and industrial robot. Because of difficulties in designing a milling machine in accordance with the plastic mock-up, Professor Allen developed an innovative design for a polar-coordinate milling machine.

It was about this time that the CAM Laboratory was visited by Mr. Thomas Walsh, AFOSR for the purpose of exploring possible mutually beneficial research interests. As a follow up of his visit, an unsolicited proposal was submitted to AFOSR on November 6, 1981 to fund a 24 month grant for continued development of the Mini-Lab and to then use the apparatus so developed in research directed toward development of an integrated Manufacturing Information System.

The projected Manufacturing Information System research was described as including three phases. Phase I included the development of suitable appartus, PhaseII includes development of software exchange specifications, standards, integration software, and necessary architecture models, and Phase III included subdividing the responsibility for creating applications programs among a number of research institutions.

Some slippage occured in meeting this planned schedule because the principal investigators did not realize that the project was funded on an annual basis rather than on the 24-month basis as planned. Subsequently, a continuation proposal was prepared and submitted July 14, 1983. A no-cost extension was approved as was funding for the completion of Phase I of the project.

The following sections describe the work performed to date, new contributions of hardware from industry, plans for completing Phases II and III and a brief summary.

1.3 MISSION AND GOALS: The mission of the Manufacturing Information System is to develop and test scaled-down manufacturing equipment and systems as a basis for manufacturing education, manufacturing research, and manufacturing simulation studies. Eight goals for accomplishing the stated mission have been identified. Only the three goals for Phase I are shown here:

Goal 1. Design and develop laboratory-size prototype production equipment for processing and handling of box-like, sheet, and rotational parts made from metallic and non-metallic materials.

Goal 2. Design and develop a small, microprocessor-based, computer numerical control (CNC) system for controlling processing and handling equipment.

Goal 3. Develop and test the CAD/CAM interface between a small computer graphics display device and the CNC processing and handling system.

1.4 PROGRESS TO DATE: Although the development of an Intergrated Manufacturing Information System is a very large task, progress to date has been most gratifying. The following subsections describe specific activities:

1.4.1 ARCHITECTURE: The architecture model for the Integrated Manufacturing Information System is shown in Fig. 1. This model reflects the substitution of an IBM PC-XT for the Tektronix 4052 Microcomputer as approved. A change to the IBM PC has been found to be an excellent choice because of the vast amount of software available for this system.

1.4.2 TECHNICAL ILLUSTRATION: The technical illustration, Fig. 2, is intended to show how the various pieces of the Manufacturing Information System are to be arranged for education, research, and simulation studies.

1.4.3 PHOTOGRAPH OF MANUFACTURING INFORMATION SYSTEM: Fig. 3 shows an overall view of the laboratory apparatus used in the manufacturing information system. Around the perifery are interconnected computers tied through an electronic multiplexer switch to a common data base. In the center of this photograph are shown the automated storage and retrieval system (AS/RS), the 8-station turret punch, and 6-axis stepper motor controllers (Left rear).

1.4.4 ENGINEERING DESIGN TERMINAL: The engineering design terminal shown in Fig. 4 provides both a monochrome menu display and a color graphics display. A three-dimensional graphics software package and tablet/arm have been ordered using university funds for use with this equipment. Composite parametric designs based on group technology principles are to be implemented with this system, along with a bill of material processor, master scheduling system, market forecasting, and management spread-sheet software . A new version of the popular BYU Part Family Classification System is being developed and will be implemented on this terminal using the powerful DCLASS^{tm} Multipurpose Tree-processor System.

1.4.5 PROCESS PLANNING, SCHEDULING, AND CONTROL TERMINAL: The terminal shown in Fig. 5 is an IBM PC-XT with a 10-mb hard disc and 256k memory. It is used to generate process plans based upon pre-stored decision-tree logic. This terminal is connected to the engineering design terminal via the multiport controller (Right) from which it receives family part codes and parameter values required to generate machine motion commands. This terminal will

eventually be equipped with software for scheduling and MRP (Material Requirements Planning).

1.4.6 PROCESS CONTROL COMPUTER: The Apple II^e and shared corvus 10-mb disc is shown in Fig. 6. This system receives command data from the process planning, scheduling, and control computer. This data is then used to generate a series of motion statements to produce, inspect, assemble, and handle a given piece part.

1.4.7 SIX-AXIS STEPPER MOTOR CONTROLLER AND POWER SUPPLY: The digital stepper motor driver and power supply is shown in Fig. 7. This power supply is capable of coordinating motions of up to six stepper motions at rates of up to 3000 steps per second. This provides capabilities for both feed rates and rapid positioning rates for the miniature equipment.

1.4.8 AUTOMATED STORAGE AND RETRIEVAL SYSTEM (AS/RS): The bin-type AS/RS System, Fig. 8, is powered by the stepper motor controller under command from the Apple II^e process control computer. The process control computer is in turn connected via the electronic switch to the IBM PC. A current program displays the bin layout on the graphics terminal and permits the user to easily select any two bins and move them to their delivery stations, then return them to their originating positions. Raw stock and in-process inventory may be stored in the bins.

1.4.9 EIGHT STATION TURRET PUNCH: The turret punch shown in Fig. 9 is used to produce sheet parts from soft materials such as plastic, cardboard or thin metals. Sheets of 4"x 8" can be punched with various diameter or various shaped holes depending upon which tools are in the tool turret. Some additional work must be done to increase punching capacity and punch alignment.

1.4.10 POLAR-COORDINATE MILLING MACHINE: The polar coordinate milling machine is nearing final stages of construction as shown in Fig. 10 and 11. The over/arm is shown being machined in Fig.10 in which a v-groove is being added for the track rollers. Fig. 11 shows the base plate and cartridge for the moveable, rotary table which may be positioned beneath the over/arm of Fig. 10.

1.4.11 INDUSTRIAL ROBOT MANIPULATOR: Various component parts of the 5-axis industrial robot manipulator are shown in Fig. 12, including the rotary base, elevating mechanism, and stepper motor mounting plates.

1.5 NEW HARDWARE CONTRIBUTIONS: Howlett-Packard has recently donated several pieces of equipment for the Mini-Lab including a High Resolution Graphic and Engineering Workstation (H.P. 9836C) with a 20-mb disc, and an 8-color pen plotter (H.P. 7580). This powerful system will initially be used as a factory manager and as an advanced workstation for engineering analysis. The computer will be equipped with the UNIX operating system with multi-tasking capabilities. The Lab is also on the verge of installing an HP 3000 computer system which, in this instance, will simulate the corporate computer in a distributed hierarchal system.

Evans and Sutherland have replaced our black and white graphics system with their new PS330 color graphics system, and a license is being negotiated for the Romulus solids modeling software package. This new equipment will greatly extend capabilities for process modeling and simulation as well as doing work on database development and database management, as part of the Manufacturing Information System research.

2. PLANS FOR COMPLETING PHASE I

2.1 TASKS TO BE PERFORMED: The tasks remaining include completing 6.3, robot fabrication, 6.5, milling machine fabrication, 8.0 interface development, and 10.0 integrating and testing of hardware and electronic communication system.

The robot fabrication is progressing well and should be completed within 8 weeks. Essentially, all components for the polar-coordinate milling machine have been fabricated and it is ready for assembly as soon as a few more purchased components arrive.

Interface development is proceeding smoothly. Standard N/C commands have been selected for each piece of equipment and a machine code interpreter is being written in assembly language for the Z-80 microcomputer which is installed in each Apple II^{e} process control computer. This program is designed to accept a command string from MBASIC (the selected standard programming language), send this string character-by-character to the stepper motor controller and take care of all handshaking signals from the motor controller.

2.2 CHANGES TO ORIGINAL PLAN: In Fig. 13 is shown a schematic for the CNC Lathe for which preliminary design work has been undertaken. When the project was initiated there were no miniature CNC Lathes commercially available. Since that time, however, two or three quite good machines have become available which it is believed can be incorporated in with equipment now completed or nearing completion. Consequently, we are proposing that industrial development funds be used to purchase and integrate commercially available lathe hardware into the system. There is still remaining the need to develop the tool changer but that is a relatively minor problem. The cost of a good commercially available miniature lathe is around $8,000-$9,000 including the controller. Since we have developed our own controller that could be omitted if the vendor wishes to provide a machine without its controller. We are looking for sources of industrial funding for this piece of equipment.

2.3 SCHEDULE: The revised work schedule reflecting the 28 month duration of the project is shown in Fig. 14. Completion dates for Robot and Milling Machine Fabrication have been rescheduled as well as projected purchase and intergration date for a CNC lathe. Interface development, demonstration software development, and final intergration and testing have been extended in accordance with the revised schedule.

2.4 BUDGET: The budget for 1983-84 is shown below. It remains unchanged from the amount requested and awarded.

WAGES AND SALARIES

	1st YR (1982-83)	2nd YR (1983-84)	TOTAL
Principal Investigator No. 1 D. K. Allen (5% F.W./SU.-20% 2nd Yr.)	1,800	3,500	5,300
Principal Investigator No. 2 P. R. Smith (25%)	5,000	6,000	11,000
Principal Investigator No. 3 M. J. Smart (100% SP/SU)	9,000	5,000	14,000
Research Technician V. L. Dearden (25%)	9,000	5,000	14,000
Part-time Students	1,200	15,000	16,200
TOTAL WAGES & SALARIES	$26,000	$34,500	$60,500
Fringe Benefit (12% of W&S)	3,120	3,900	7,020
Travel	800	800	1,600
Supplies	7,000	3,000	10,000
*Consultant (1) F. Blair	10,000	-	10,000
Publication/Telephone/Postage	1,000	500	1,500
TOTAL DIRECT COSTS	$47,920	$42,700	$90,620
Indirect Costs (39.5% of Direct)	16,700	16,870	33,570
Capital Equipment	27,000	-	27,000
PROGRAM TOTAL	$91,690	$59,570	$151,260

*(1) The consultant, Mr. Blair is an experienced designer and technical illustrator who has already developed assembly and detail drawings for some of the CAM Mini-Lab. He is giving a special rate to us of only $10.00/hour. We do not believe it is possible to match this rate and quality of work by any other method.

3. INITIAL PLANS, PHASE II

3.1 PROTOTYPE PRODUCTION: As outlined in the original proposal the plan for Phase II was to revise equipment specifications and designs as required to economically produce multiple copies of the equipment for use by selected research institutions. This is still our plan, however, we would like to find a responsible organization to carry this project for us rather than being directly involved with promotion, shipping, ar˙ servicing the equipment.

3.2 SOFTWARE SPECIFICATIONS: One of the im tant goals for Phase II is to develop specifications and documentation guic ..nes for demonstration and research software. This work is very import in order to produce compatible software required as part of the Manufactur , ‾formation System.

3.3 INSTITUTION SELECTION: A few institutions with noted manufacturing education and research programs will be invited to join a computer and integrated manufacturing (CIM) Research Council for purposes of modeling, simulating, developing, and testing of advanced manufacturing information system concepts. Each institution will be responsible for acquiring necessary funding for their own equipment and for conducting research in prearranged areas.

3.4 TRAINING SYSTEMS INTEGRATION: One new activity which has been undertaken in conjunction with the development of miniature laboratory equipment is that of incorporating an operator training system.

For the past 3½ years the Manufacturing Consortium, a group of industrial companies and educational institutions, have been developing a series of educational modules for in-plant training and academic use. The modules are designed to be used by managers, designers, manufacturing engineers, and industrial engineers.

The plan is to integrate these training materials into the Manufacturing Information System and provide interactive training through the use of videotape, videodisc, and computer aided instruction. Although equipment is now on order for carrying out this integration effort, much application programming, testing, and evaluation needs to be done to actually have a useful and practical system.

4. INITIAL PLANS, PHASE III

4.1 SOFTWARE DEVELOPMENT: In Fig. 15 is shown the BYU model for computer integrated manufacturing. This model shows major functional activities of the company grouped into eight major divisions: (1) Product design, (2) Materials/purchasing, (3) Manufacturing engineering, (4) Production scheduling and control, (5) production operations, (6) Quality assurance, (7) Management (including policy making, financial, legal and personnel services), and (8) marketing.

The Manufacturing Information System is intended to tie the enterprise together by facilitating the activities shown within the concentric circles at the center of the diagram. These systems activities include: (1) Coordination, (2) Planning, (3) Scheduling, and (4) Control of activities shown radially within the eight major divisions.

Also shown are three other essential features of the Manufacturing Information System, namely: a common data base, a communications system, and a distributed computer processing system comprised of both central and distributed data bases.

While development and integration of production equipment, computing systems, and communications systems are very important, data base development is probably the most crucial. Many companies are jointly working to develop distributed computing and local area networking for electronic communications, but who is working on the common data base? The answer is that each company must do their own. There are probably some common elements, but by and large, each company must shoulder their own burden of data base development. Why is this? It is because each company produces different products, uses different materials, has different organizational policies and needs, and does business in a different way.

In spite of the above differences staff at this Cam Software Research Laboratory have noted similarities between companies. First, they use commonly available engineering materials. Second, they purchase their equipment and tooling from common vendors, third they purchase their fasteners, bearings, and electronic components from a finite number of distributors. From the realization that many elements are common with organizations the Cam Software Research Laboratory has produced what they term a "Transportable Data Base Structure". This transportable data base is essentially a series of hierarchal tree structures for classifying and coding parts, materials, processes, equipment, tooling, etc, etc. These tree structures may be readily tailored to meet the needs of a given company.

The transportable data base structure will be used as an integral part of the Manufacturing Information System as implemented and tested in the CAD/CAM Mini-Laboratory environment.

4.2 SOFTWARE EXCHANGE: As each of the manufacturing education and research groups gets their equipment installed and areas of research assigned, they will be provided with software documentation standards, keyword glossary, and copies of the transportable data base structure, the DCLASS multi-purpose tree processor, and an integration tool kit.

Each group will then be expected to commit resources and effect to developing, and testing software for assigned application programs. At the end of a pre-arranged development period, research groups will meet, demonstrate their application programs, and explain their documentation. Awards will be presented for various categories of applications programs; software and documentation will then be exchanged to complete goal number 8 as defined in the original proposal. The

final test of the entire program is defined by Goal No. 8 which is "to explore transferability of principles, concepts, and software designs from the CAD/CAM Mini-Lab environment to full-size CAD/CAM systems operating in a real world production environment". Each research organization will be expected to work with local companies and organizations in carrying out this goal.

5. SUMMARY

This technical report first provides a brief review of the development of a full-size CAD/CAM Laboratory at Brigham Young University. Second, it describes the subsequent development of a miniature CAD/CAM Laboratory in which integration concepts and manufacturing information system concepts (funded under this Grant) are being carried out. Third, it sets fourth plans for completing Phases II and III. The final test will be how well manufacturing research groups are able to work with local industry and transfer research result from the laboratory setting into the real world production environment.

D.K. Allen, P.R. Smith, M.J. Smart
Principal Investigators
CAM Software Research Laboratory
Brigham Young University
24 December 1983

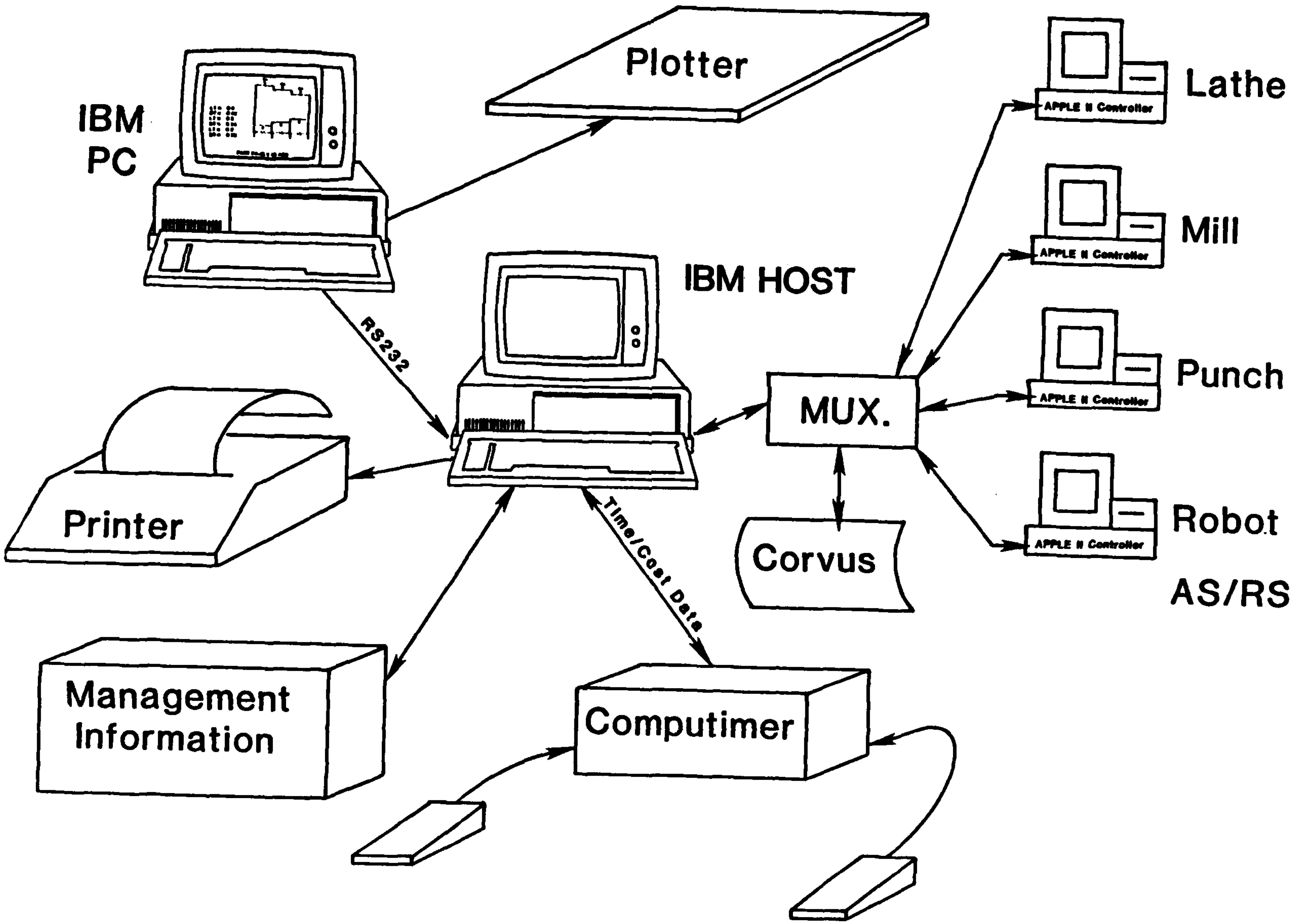

Fig. 1. Architecture for Integrated Manufacturing Information System

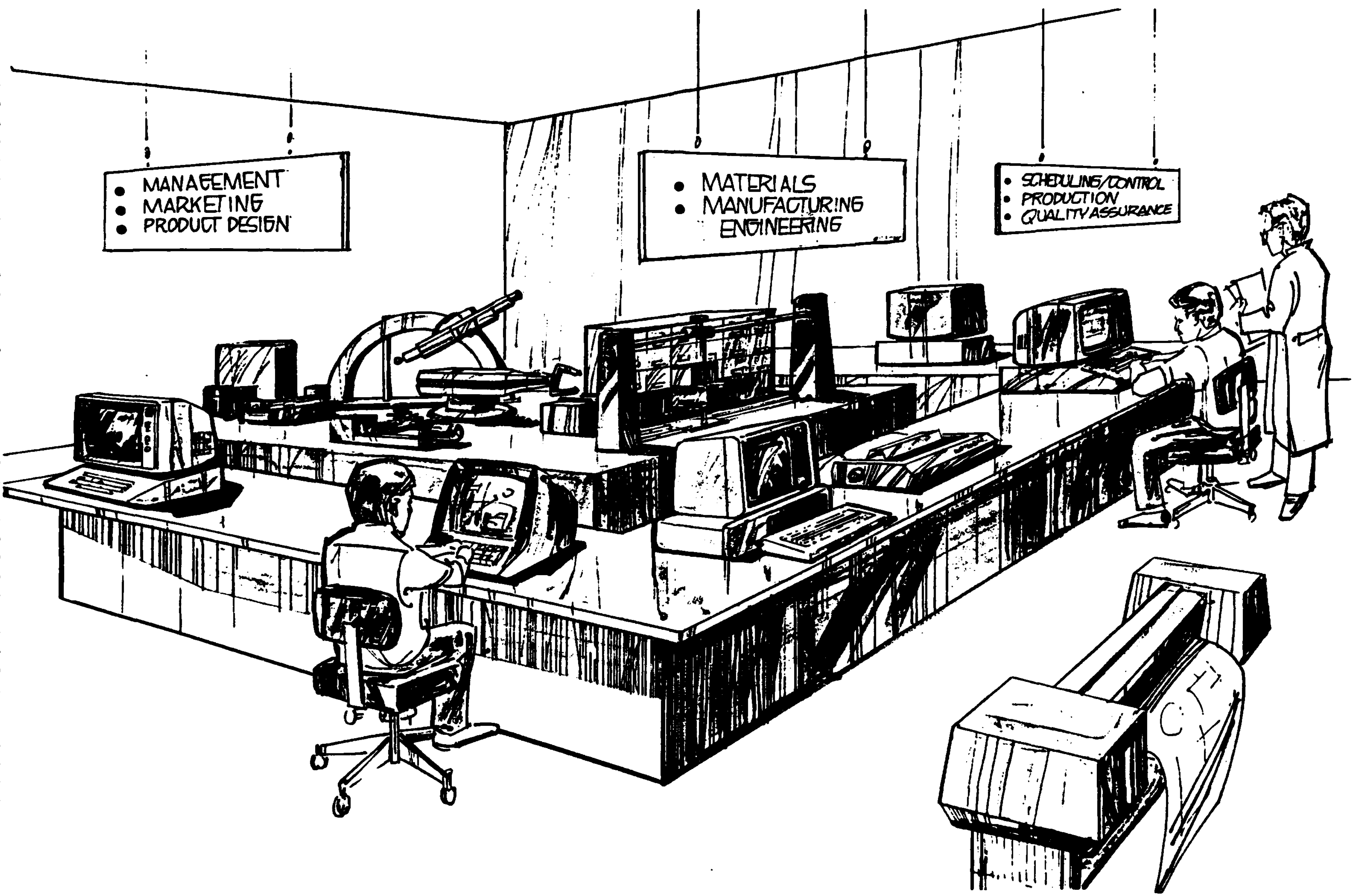

Fig. 2. Technical Illustration Showing Integrated Manufacturing Information System

Fig. 3. Photograph of Manufacturing Information System

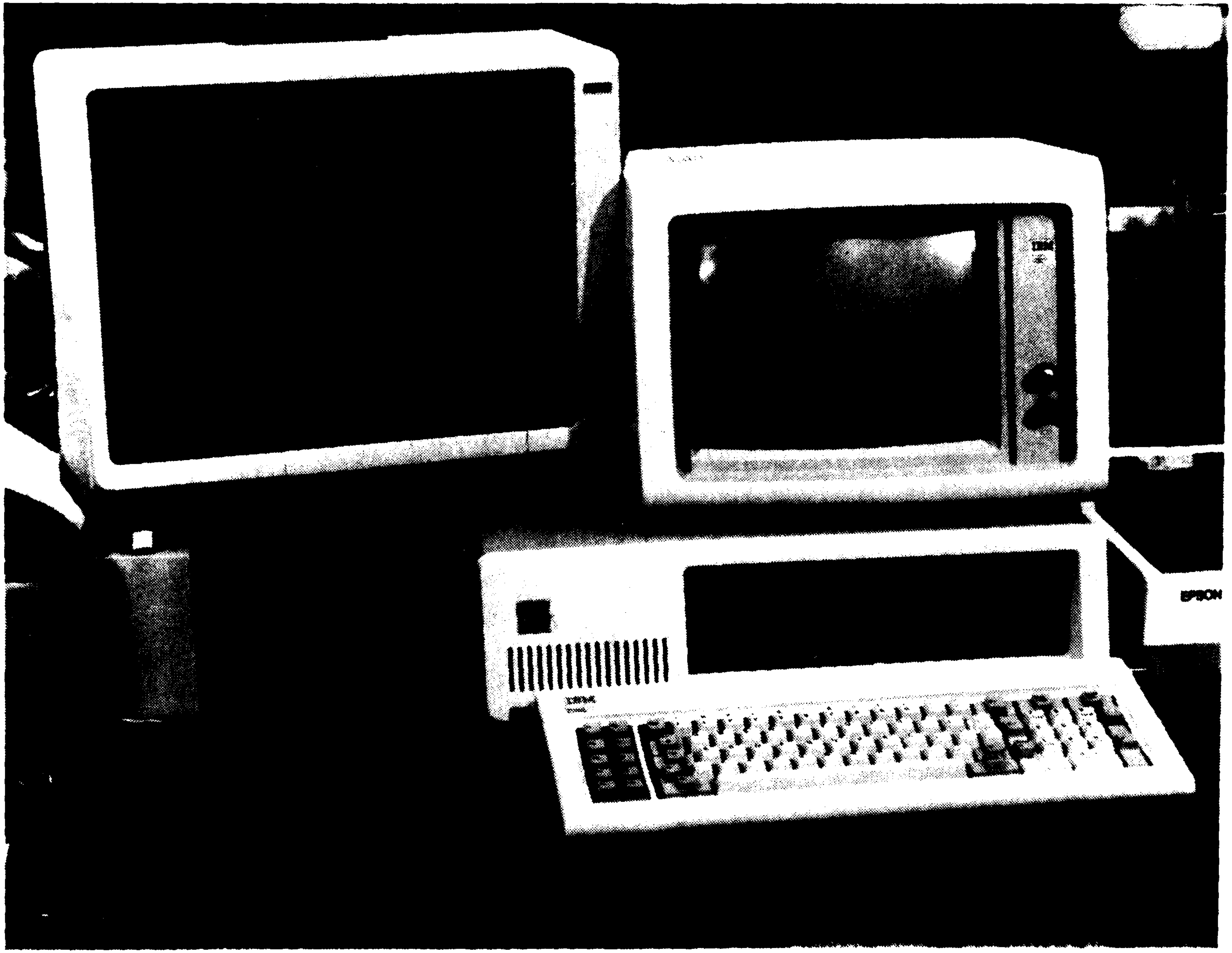

Fig. 4. Engineering Design Terminal with Monochrome and Color Graphic Displays

Fig. 5. Process Planning, Scheduling, and Control Terminal

Fig. 6. Process Control Computer and Shared Winchester Disc.

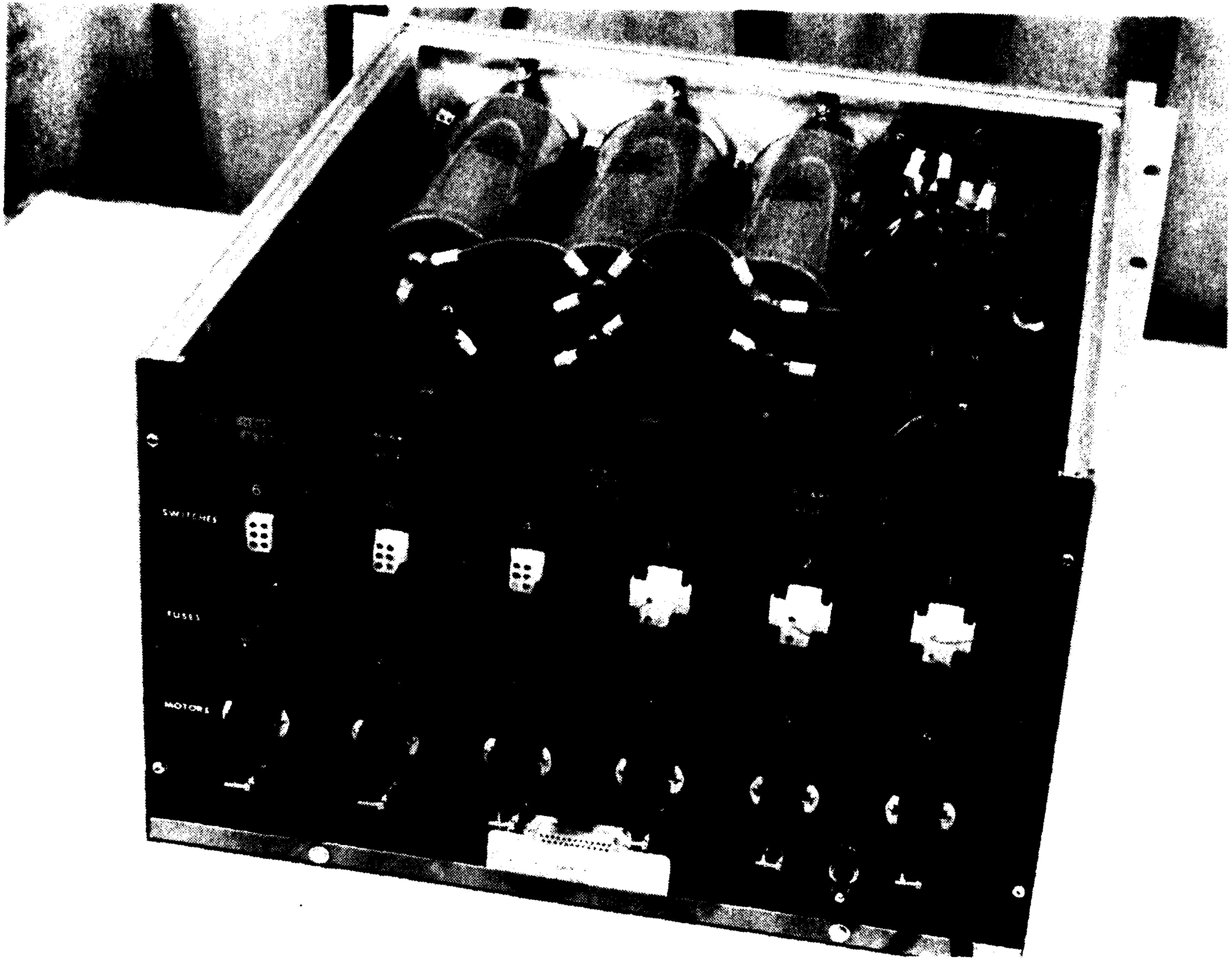

Fig. 7. Six-Axis Stepper Motor Controller and Power Supply

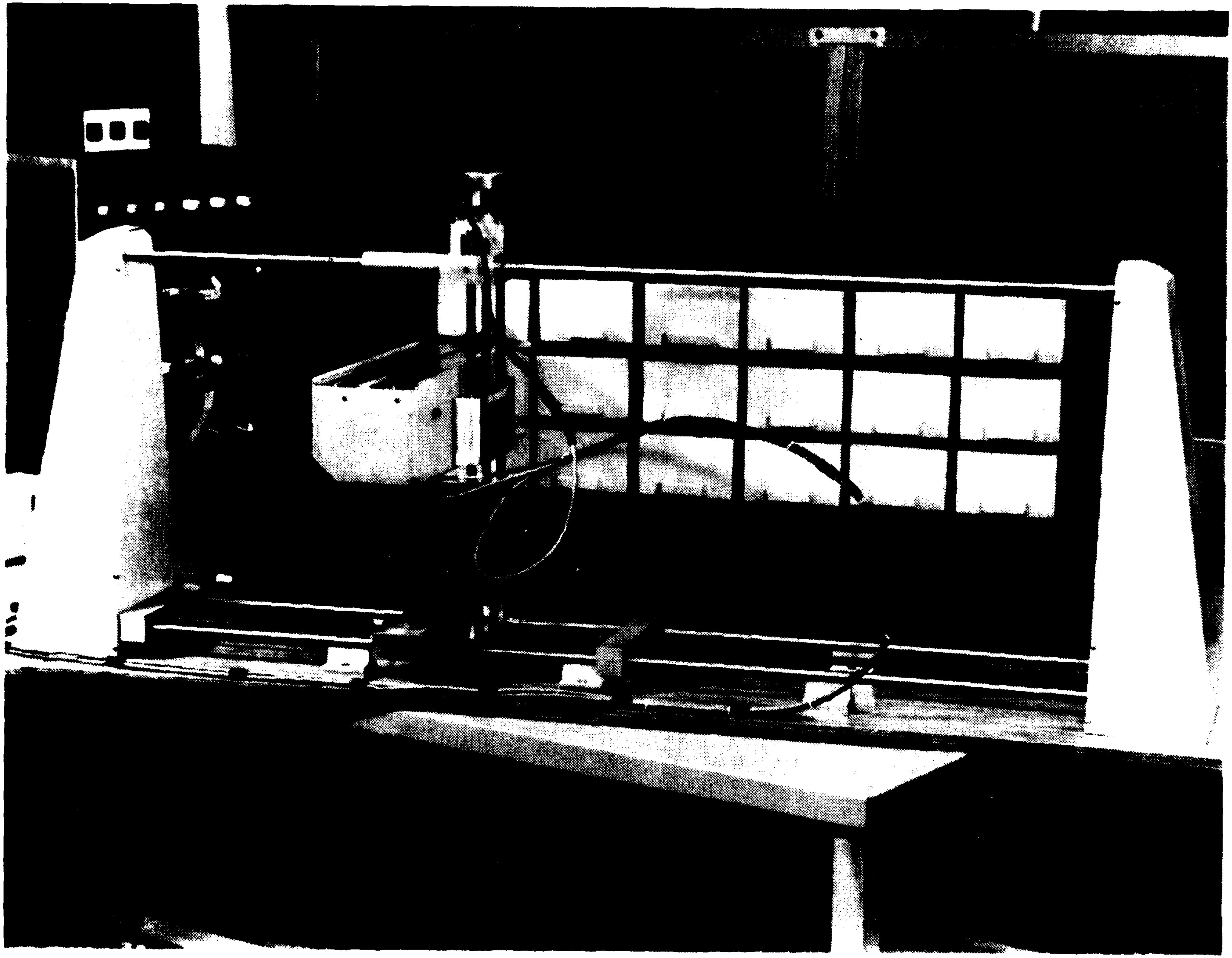

Fig. 8. Automated Storage and Retrieval System (AS/RS)

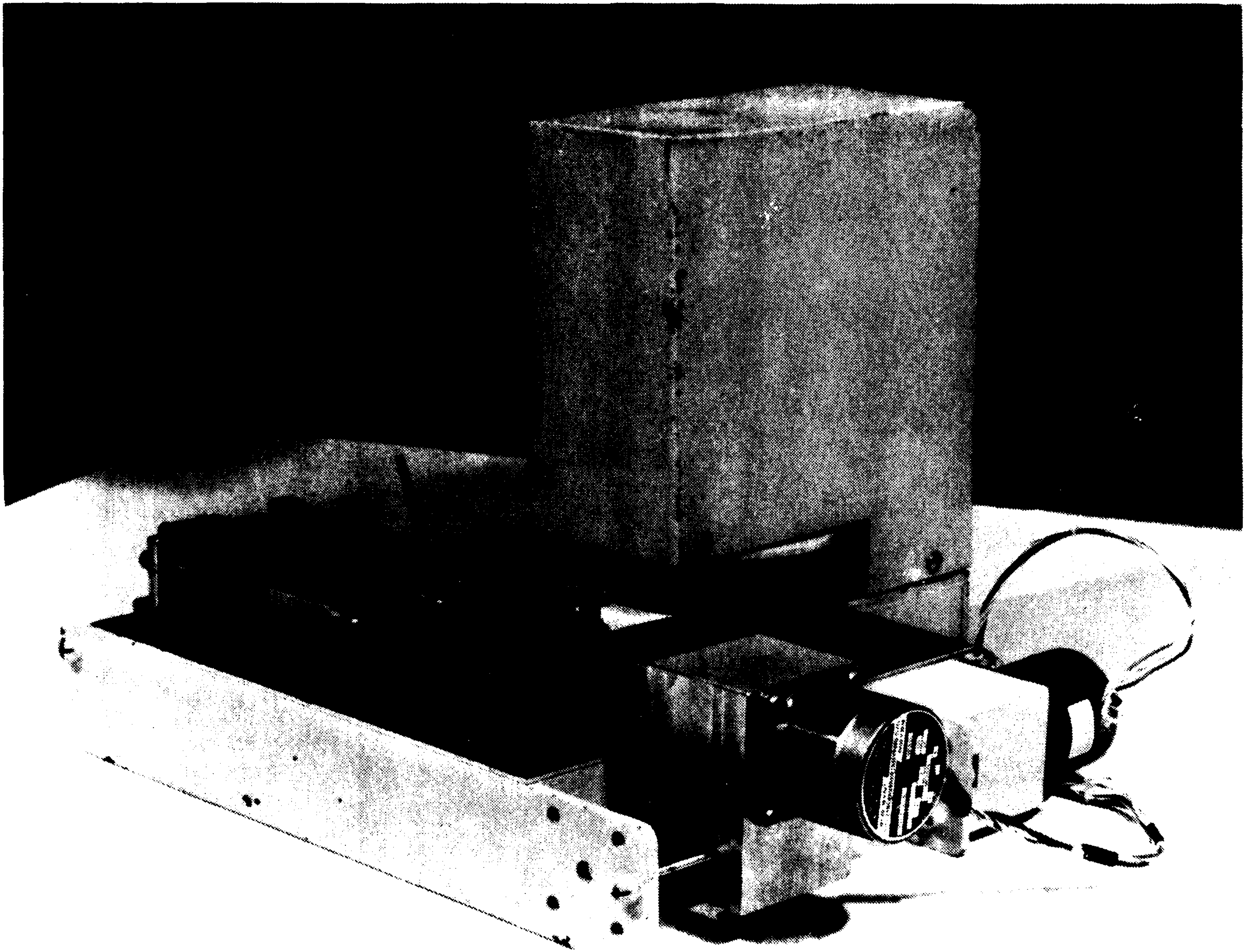

Fig. 9. Eight-Station Turret Punch

Fig. 10. Overarm Being Machined for Polar-Coordinate Milling Machine

Fig. 11. Base and Table Carriage for Polar Coordinate Mill

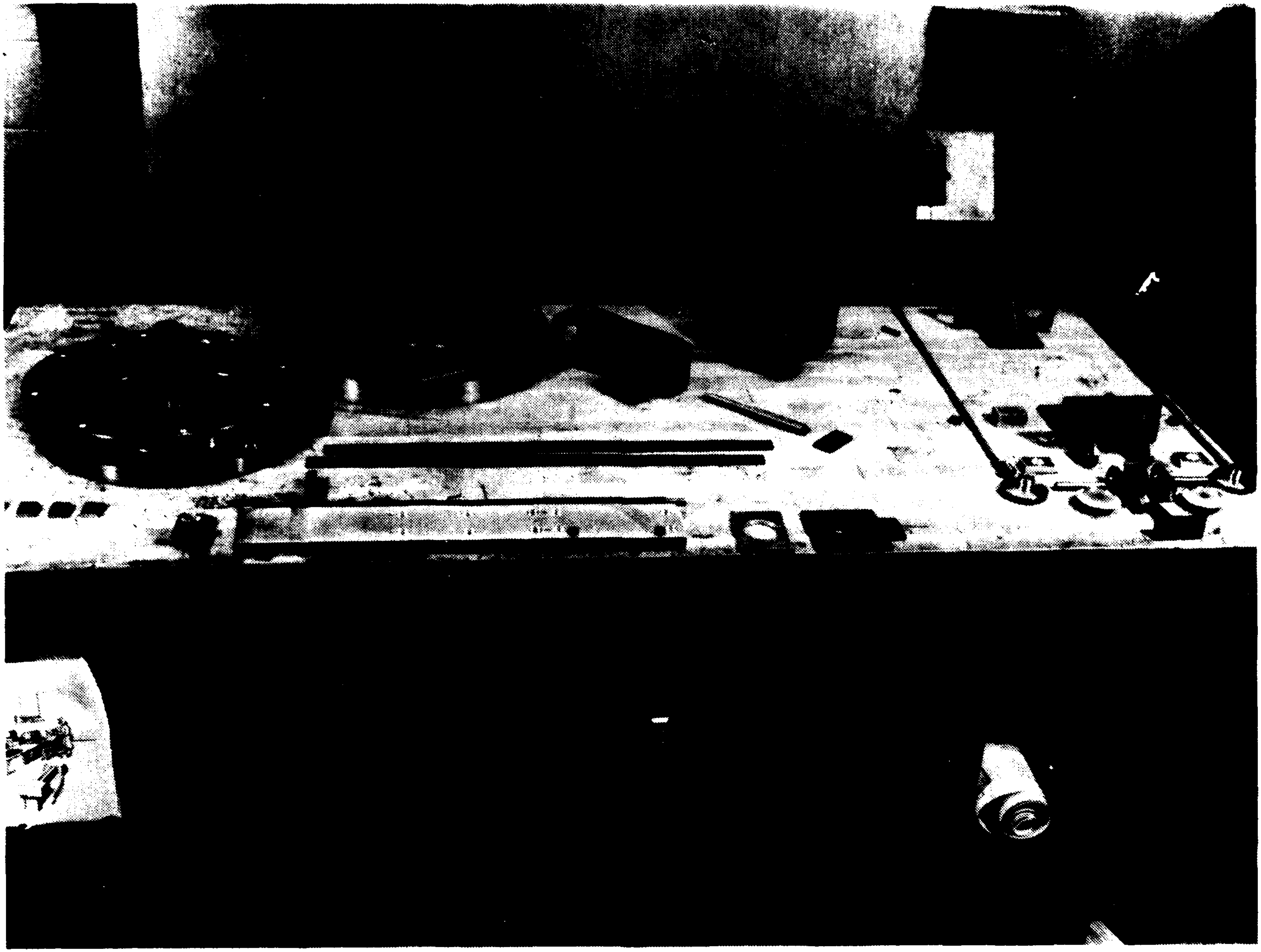

Fig. 12. Component Part for Industrial Robot Manipulator

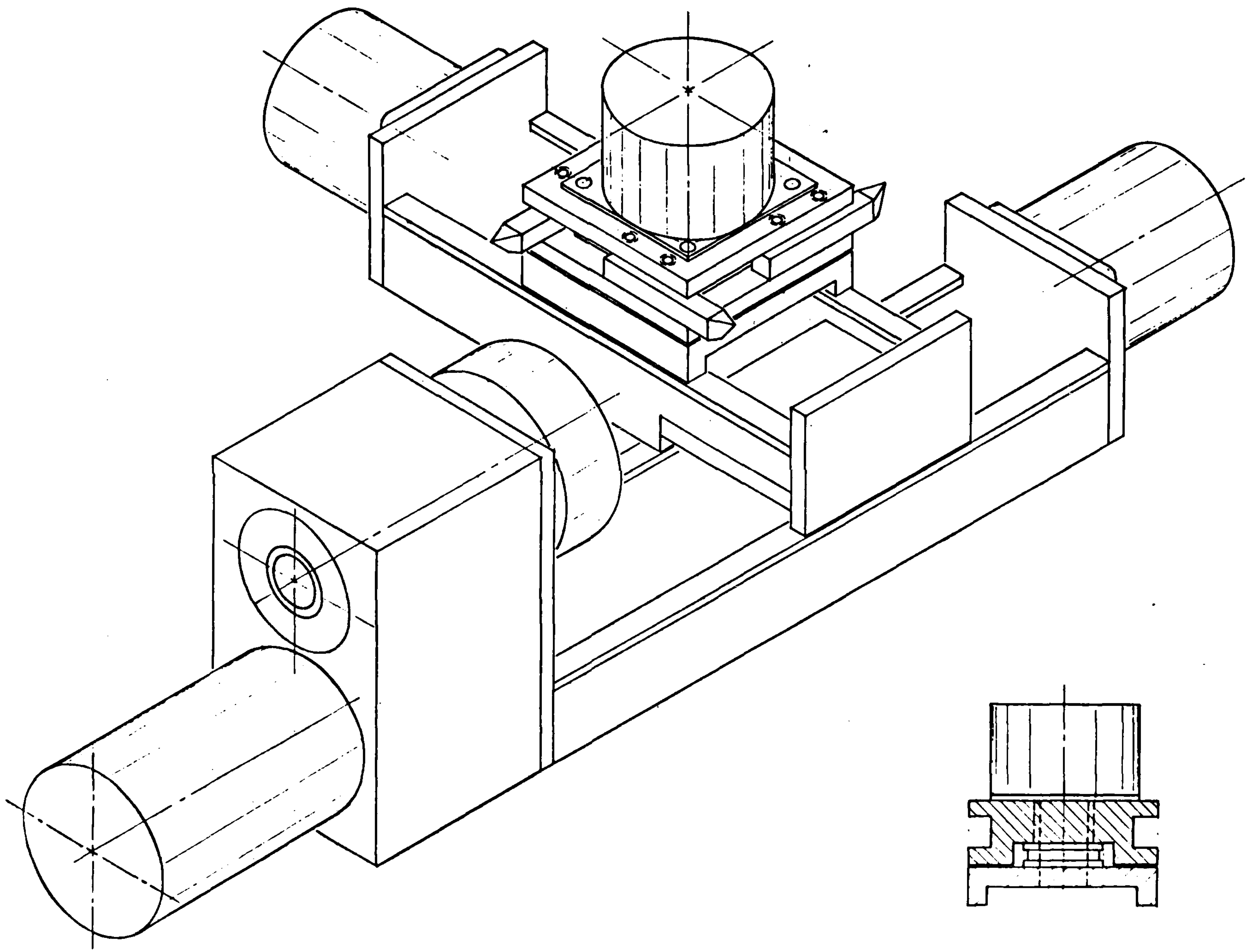

Fig. 13. Sketch of Computer Controlled Lathe

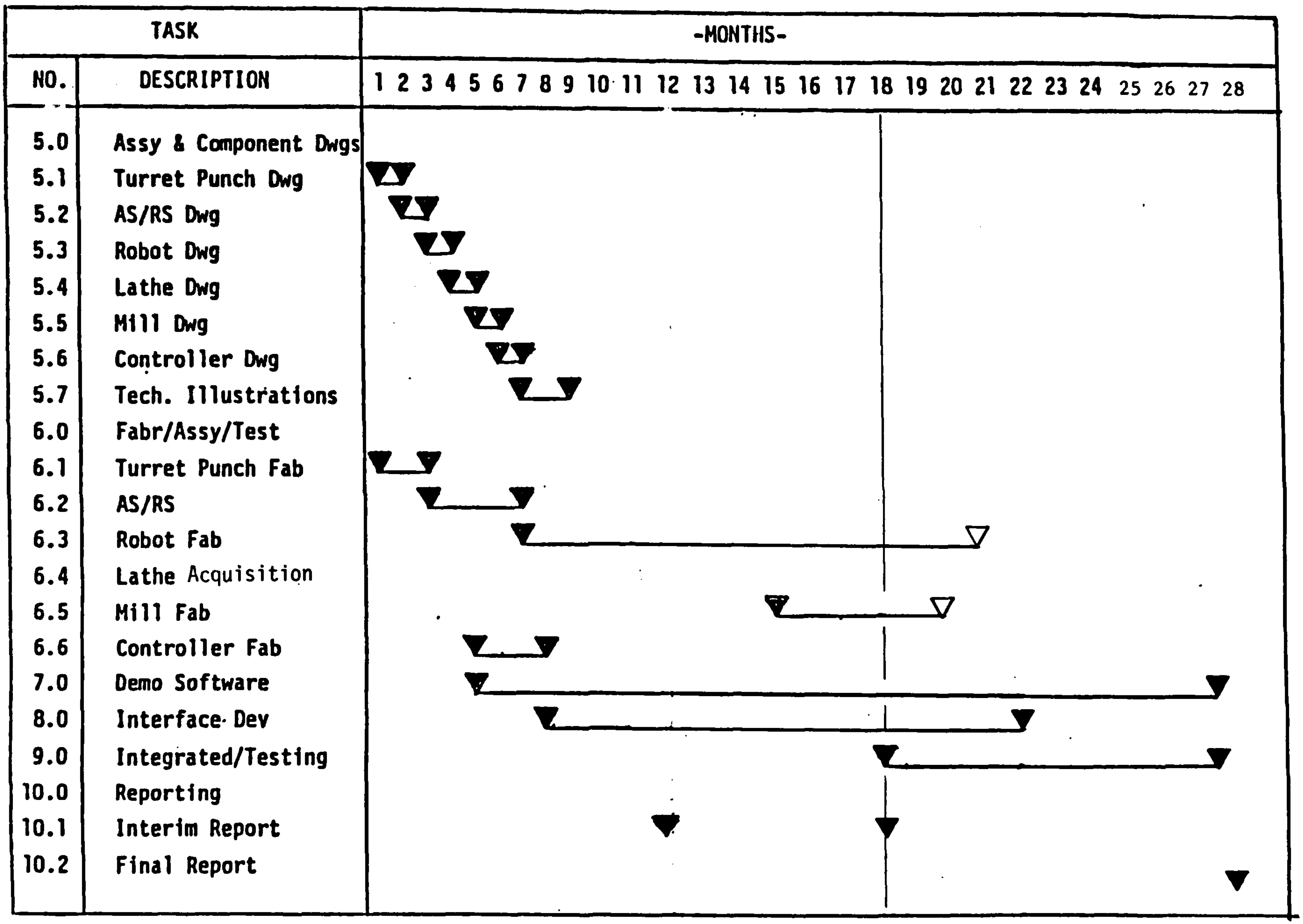

Fig. 14. Revised Work Schedule for 28-Month Project

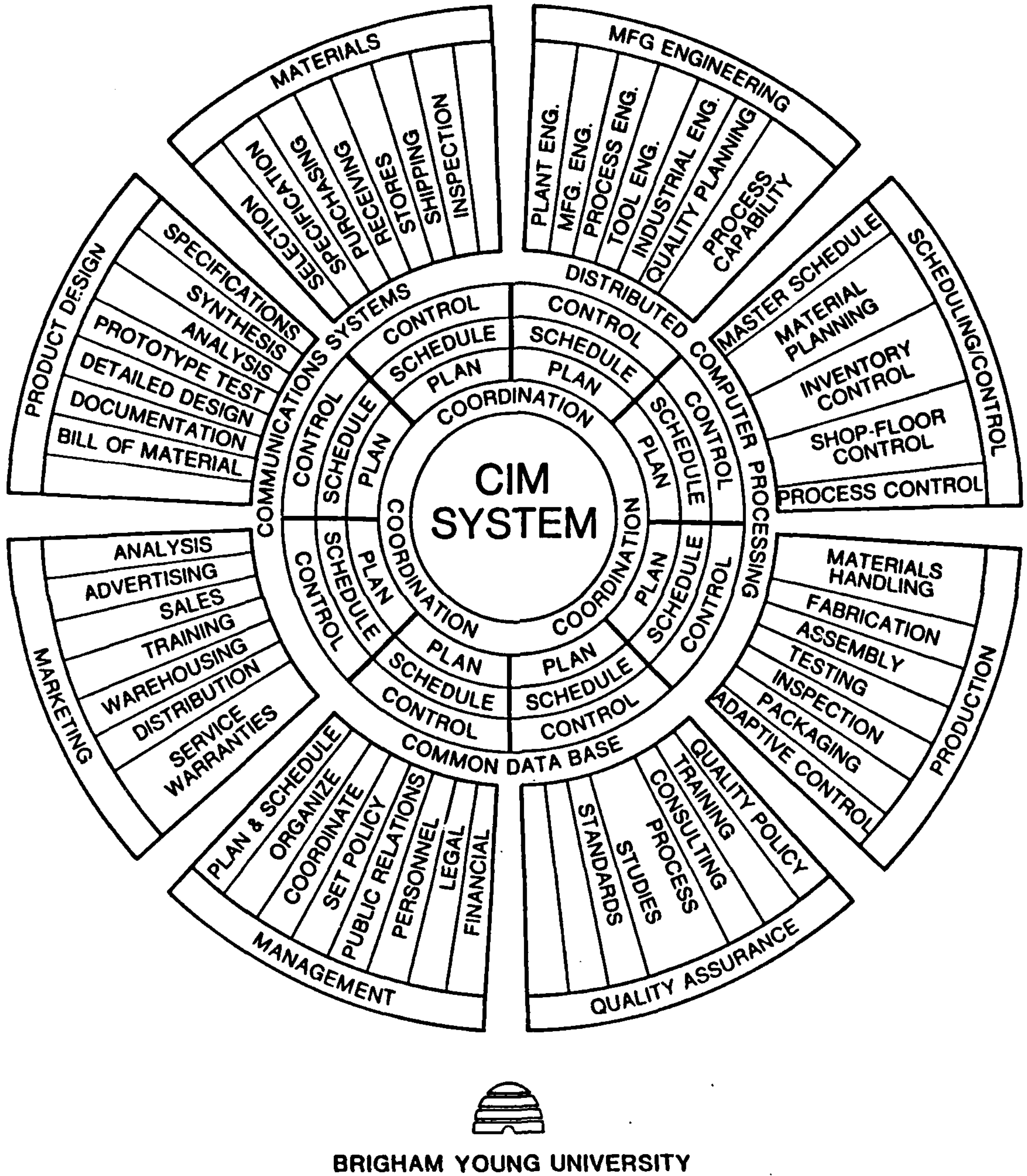

Fig. 15. COMPUTER INTEGRATED MANUFACTURING

R7-6-83

APPENDIX A

FIRST INTERIM REPORT

July 14, 1983

For the Period 82 July 01 Through 83 Sept. 30

FIRST INTERIM REPORT
MANUFACTURING INFORMATION SYSTEM

Submitted to

Air Force Office of Scientific Research
Building 410, Room 223
Bolling Air Force Base
Washington, D.C. 20322 N.C.

July 14, 1983

For the Period 82 July 01 Through 83 Sept. 30

Principal Investigators:
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Brigham Young University
Provo, Utah 84602

MANUFACTURING INFORMATION SYSTEM

1. Purpose

This report provides a brief historical background on the development of laboratory sized N/C machines and material transport systems and then results of AFOSR grant #82-0253 for development of a manufacturing information system.

2. Scope

The report focuses on development of miniature manufacturing equipment, machine tool controllers, and supporting microcomputer systems required for a fully integrated manufacturing information system. The miniature facility is intended for mechanical piecepart fabrication, inspection and assembly.*

Mechanical pieceparts include rotational, box-like, and sheet parts made from easily-machined materials such as aluminum, brass, nylon, styrofoam, machinable wax, anad sheet and cardstock plastic.

3. Historical Background

The development of miniature manufacturing facilities has evolved and expanded over several years and has involved a number of institutions and many people.

3.1 Miniature Positioning Table. The first published record that came into the hands of the author described the design and construction of a miniature machine-tool device for instructional use. This report dated 15 November, 1961, was entitled "Punched-Tape Numerically Controlled

*A proposal for extension of the Manufacturing Information System to Electronic Computer-Aided Manufacturing (ECAM) is being prepared and will be submitted to various funding agencies, including AFOSR, in the near future.

Machine Tool for Instructional Use." The project had been funded under NSF Grant 12361. The principle investigator for the project was Frank W. Tippitt, Associate Professor of Industrial Engineering at Southern Methodist University in Dallas Texas. The Tippitt design included a positioning table with 3-axes of movement (Fig. 1,2), a control cabinet, a 7-channel punched paper tape reader, and a power supply.

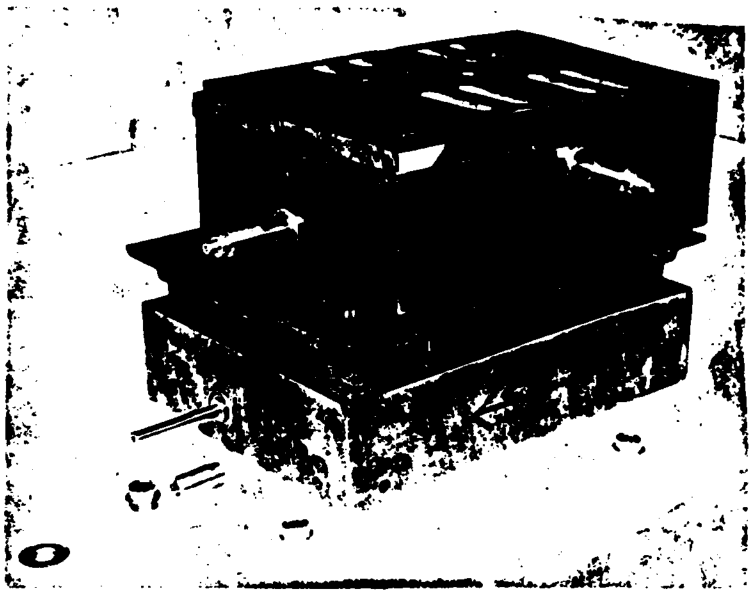


Figure 1. Three-Axis Positioning Table

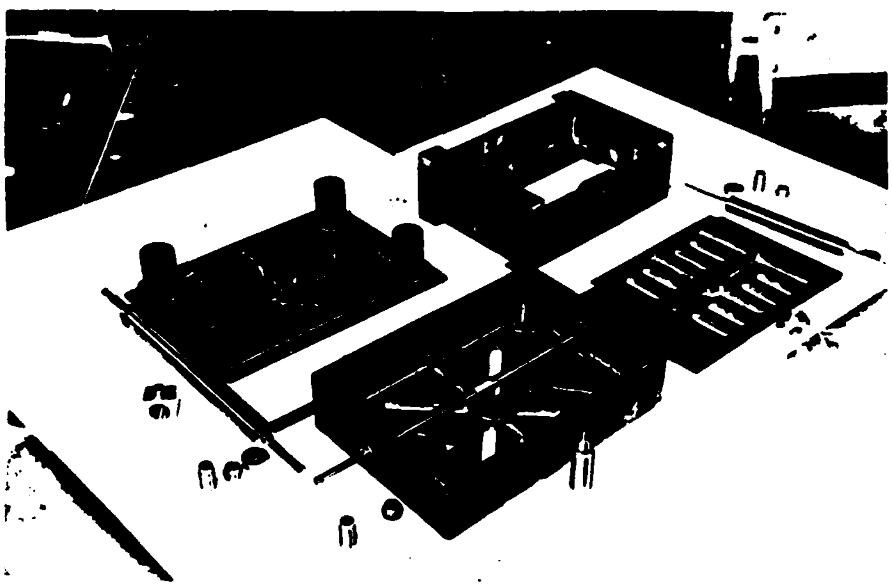


Figure 2. Components for Positioning Table

The positioning table was intended to be used in conjunction with a fixed spindle drill press. Table motions reported were x = 8", y = 4", and z = 1-1/2". Professor Tippitt suggested that a better size for instructional purposes would probably have 4" x 2" x 1" movements.

Digimotor drives were employed (opposed rotary solenoid pairs with a common shaft) with 20 steps per shaft revolution. It was reported that these drives could be operated at 15 steps per second with fair reliability to give a table motion increment of 0.0005" per step. A 3/4-10 NC lead screw was used with a worm gear reduction. This gear reduction was necessitated due to the low torque of the drive motors.

Considering the date of this project and the state-of-the-art in electronic controllers, this was quite a significant undertaking. Transistors and diodes were used extensively on the four circuit cards which had to be developed for the controller (Fig. 3). Punched tape preparation was reportedly done off-line on a separate computer system.

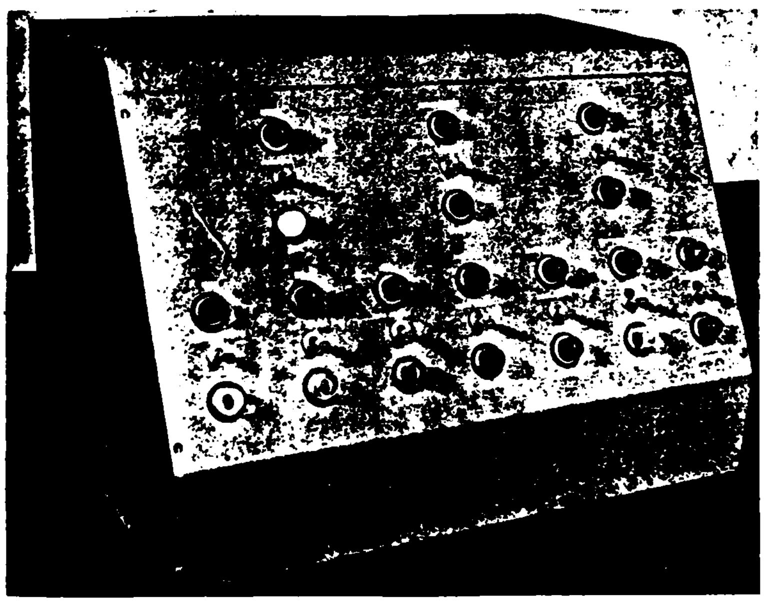


Figure 3. Positioning Table Controller

3.2 Materials Transport System. The first known work for miniature automated materials transport equipment probably started with the training system developed at the General Motors Technical Center in about 1973. This facility included a computer controlled material transport device known as a "puck-pusher." The puck-pusher consisted of an interconnected series of belts, cams, cranks, and other mechanical drive components which were powered by eight Slosyn digital stepping motors. In operation, a small metal disc ("puck") approximately 3/4" diameter by 1/4" in height was first placed on a horizontal belt. Next, commands were given to move the puck along the belt by programming the computer to issue the correct number and rate of pulses to the appropriate stepper motors. When the puck had been moved the appropriate distance, a second stepper motor was started which controlled a crank mechanism to push the puck off the belt into a hopper where it was subsequently elevated by another stepper motor and drive mechanism. In this manner, the puck was moved through various stations of the mechanism. The challenge of programming the puck-pusher was to move the puck through all stations as rapidly as possible but without accelerating it so rapidly as to throw it from the belt or to start the elevating mechanism before the puck had time to roll into correct position.

The author had the opportunity of seeing the "puck-pusher" in operation in 1975 at Caterpillar Tractor Company. The equipment had been constructed using the basic General Motors design but with Caterpillar's own design for the stepping motor controllers. The system was being controlled directly from a PDP11/20 mini-computer. The mini-computer also was connected to a small Calcomp drum plotter. The system was being used in conjunction with a 1-day management training program in which attendees had the opportunity in the morning of familiarizing themselves with an APT-like

programming language, displaying tool center-line data on the drum plotter, and then learning how to program and control the "puck-pusher." The afternoon was spent in demonstrating how the computer could be used as a simulation tool for business applications. The intent of the training program was to provide instruction and hands-on experience for the purpose of providing management with increased awareness of the capabilities and limitations of computers in the manufacturing environment.

4. Initial Concept for CAM Mini-Lab

While returning home from the Caterpillar visit, the author asked himself the question "Why not use the eight stepper motors for the 'puck-pusher' to drive equipment in an integrated miniature factory instead?" Sketches were made showing how two motors could be used for a lathe, three motors for a milling machine and three motors for a turret punch. The idea was to develop miniature equipment which could process rotational, box-like and sheet materials and tie them directly to a computer graphics system.

Funds from the Western Electric Company were used to acquire a miniature Japanese camera-making lathe (Fig. 4), a small horizontal EDM

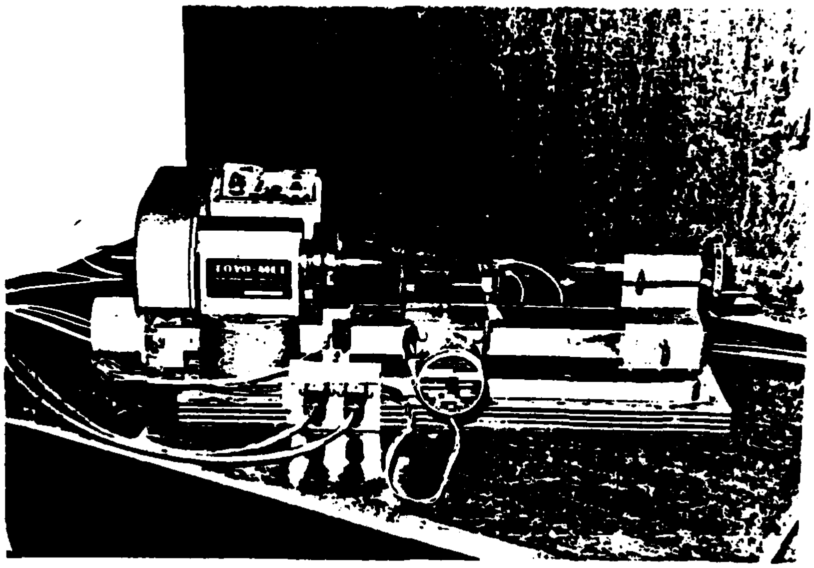


Figure 4. Miniature Camera-Making Lathe

electrode drill (Fig. 5) (which was converted to a 3-axis milling machine), digital stepper motors, power supply, and ball screws. Mr. Jack Schow was employed to adapt the ball screws to the lathe and milling machine. Tektronix Company of Beaverton, Oregon, provided a 4051 graphics display system (Fig. 6) and college funds were used to acquire a MacSym process control computer (Fig. 7).

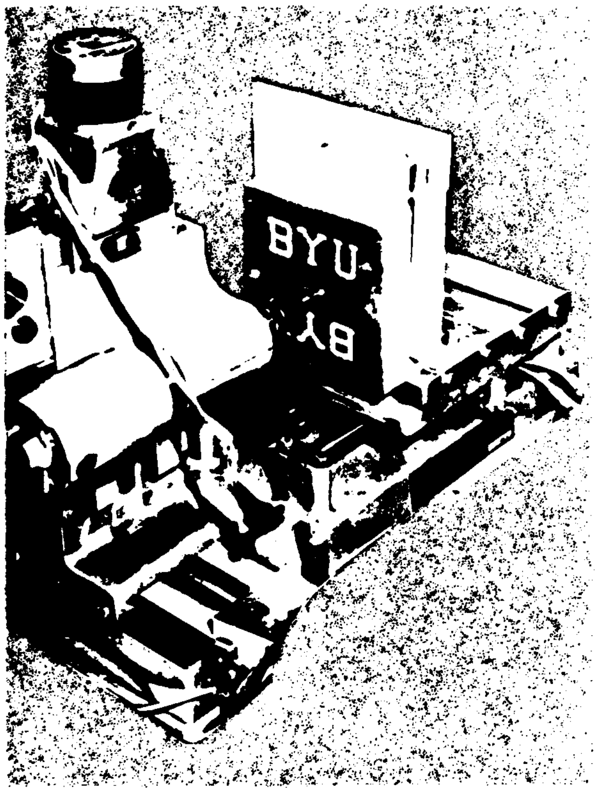


Figure 5. Miniature Mill
(From EDM Electrode Drill)

Equipment described above was utilized by Mr. Charles Snead, an electrical engineer on leave from Westinghouse, in the utilization of the initial concept for an integrated system as his thesis research for the

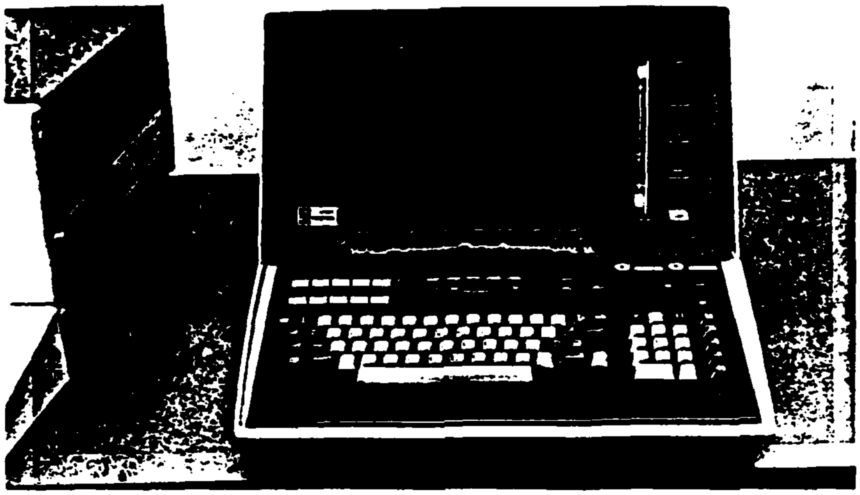


Figure 6. Tektronix 4051 Graphics System

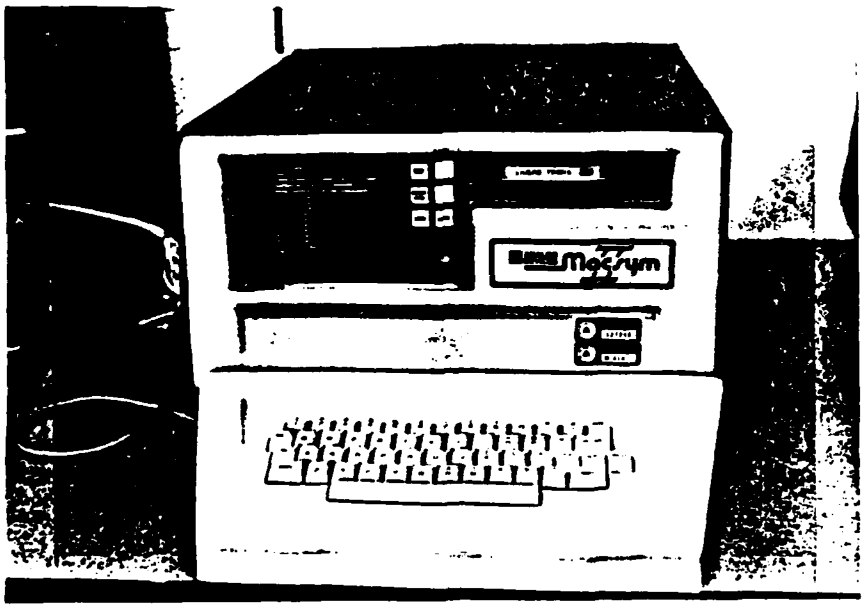


Figure 7. MacSym Process Control Computer

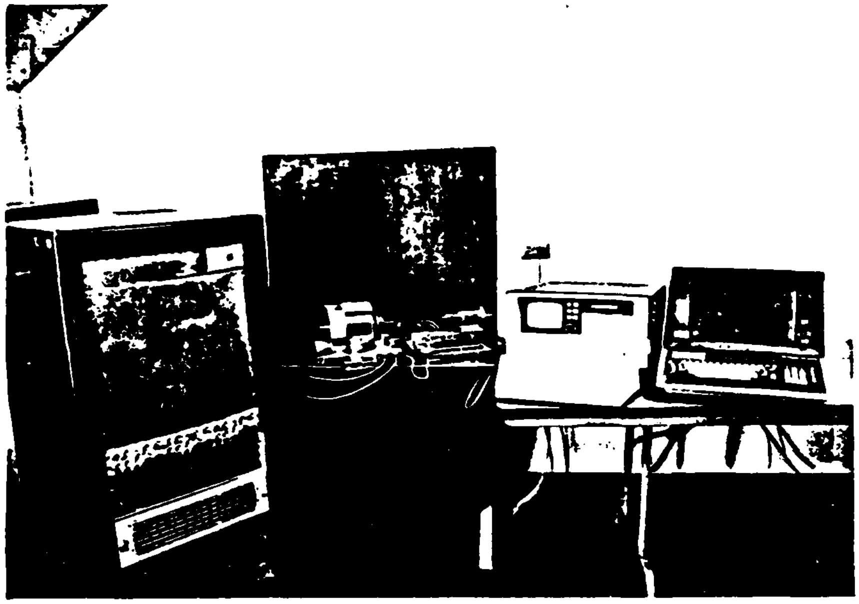


Figure 8. Initial Concept for Integrated System

Master of Science Degree in Computer-Aided Manufacturing (Fig. 8). This very significant and important research included physically integrating hardware components, and creating software for graphics, communication, and control of the equipment. The aggregate of hardware, electronics, and software was dubbed the "CAM Mini-Lab."

5. <u>CAM Mini-Lab Mockup</u>

After the first working CAD/CAM system was demonstrated in 1980, Professor Douglas Stout, Chairman of the University Industrial Design Department, was approached with the request that his students devevlop a mockup of the integrated CAM Mini-Lab. Professor Stout and 14 of his students responded. During the 1981 Spring term they spent untold hours analyzing the specifications provided to them, studying and visiting industry, preparing sketches, producing cardboard models, holding review meetings, and finally producing, beautifully finished 3-dimensional scale

models which were painted light yellow with black and red trim. These models included the following machines:

- -CNC Milling Machine
- -CNC Turret Lathe
- -CNC Laser Cutter
- -Automated Storage and Retrieval System
- -5-axis Industrial Robot
- -CNC Machine Controller

At the end of the Spring term, a special open house and reception was held for a number of invited industrial guests. Industrial Design students made short presentations regarding the equipment they had designed and produced during an intensive 8-week period (Fig. 9).

6. Miniature Robot/Controller

Funding was obtained from the Society of Manufacturing Engineers to acquire a "microbot" miniature 5-axis robot (Fig. 10), and an Apple II controller. Mr. Paul Smith, a research associate in the CAM Software Research Laboratory, was instrumental in coupling the Apple II computer to the microbot, which had been originally designed to be used with a TRS-80 computer. Paul later became involved in formulating the proposal which was submitted to AFOSR for development of the hardware and electronics required for phase I of the Manufacturing Information System, and has since been assigned as project leader for mini-lab development.

7. Challenges

As can be seen from proceeding paragraphs, the effort in moving from the concept of a miniature integrated manufacturing facility to its realization is a very significant challenge. Important steps have been taken in

BYU CAM Mini-Lab

Figure 9

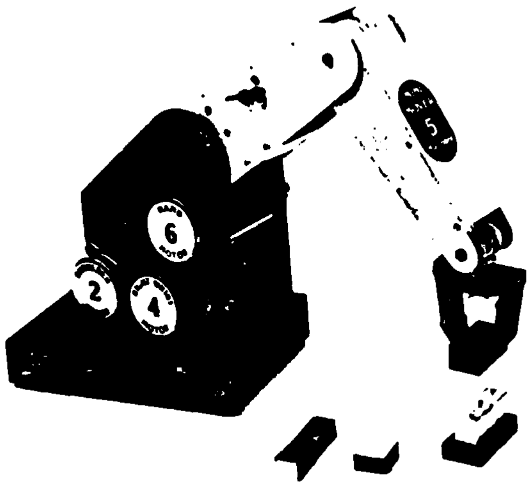


Figure 10. Mini-Mover 5 Microbot

developing enabling technology and in demonstrating limited aspects of an integrated system, but much remains to be accomplished before the fully-integrated manufacturing system, which encompasses the entire gamut of activities from design, process planning, production, inspection, and assembly, is a reality. Some of the remaining challenges include development of systems for communications, data element standardization, data collection, adaptive control, database management, coupling of basic shapes and form features with automatic graphics scaling, and development of automatic clamping and tool changing capabilities for the production equipment. One other important challenge is that of planning, scheduling, and control of system components to produce the integrated and coordinated system desired. It is believed that in a transaction-oriented system, needed for the Mini-Lab, there should be provision for 1) simulation and generative capabilities to aid in planning, 2) use of group technology principles and practices to simplify scheduling, and 3) capabilities for adaptive control to accomodate contingencies.

8. <u>Need</u>

There are a number of reasons why a miniature CAD/CAM Laboratory is desirable. The <u>first</u> and most obvious is cost. Computer controlled industrial equipment is costly. Most educational institutions do not have sufficient funds for equipment maintenance let alone acquisition costs. Even one modest-sized computer controlled machine tool can hardly be acquired for less than $50,000 without required tooling which can easily add another $20,000. Furthermore, cost of workpiece materials can be high with large industrial machines. Material cost can range from $0.50-$2.00 per pound. Few institutions have a market for finished products produced by beginning students. A <u>second</u> reason for miniature equipment is space. One CNC machine may require 150-250 sq. ft. or more of hard-to-find laboratory space. A <u>third</u> reason is safety. This includes safety to the operator as well as to the machine itself. A 20 HP machine with a revolving tool and positioning, in a rapid traverse mode can be very dangerous. Expensive safety guards, wooden fixtures, and soft styrofoam workpieces are frequently seen in educational institutions which have industrial CNC machines. A <u>fourth</u> reason why miniature equipment is desirable is because of flexibility to meet future needs. As computer controlled systems evolve, they may be easily interfaced. Machines may be easily moved and rearranged in a straight line production, flexible manufacturing, or cellular layout.

In summary, inexpensive miniature machines can be installed in relatively small laboratory spaces. Multiple copies can accomodate increased student enrollment. Equipment is safe to operate, spindle drives are in the fractional horsepower range, and positioning rates are much less rapid than full-sized production equipment.

9. Mission and Goals

The mission of the manufacturing information system is to develop and test scaled-down manufacturing equipment and systems as a basis for manufacturing education, manufacturing research, and manufacturing simulation studies. Goals for accomplishing the stated mission include the following:

Phase I

Goal 1. Design and develop prototype production equipment for processing and handling of box-like, sheet, and rotational parts made from metallic and non-metallic materials.

Goal 2. Design and develop a small, microprocessor-based, computer numerical control (CNC) system for controlling processing and handling equipment.

Goal 3. Develop and test the CAD/CAM interface between a small computer graphics display device and the CNC processing and handling system.

Phase II

Goal 4. Develop production versions of the prototype hardware and produce a number of units for installation at selected universities who are interested and capable of testing the equipment in the education and research modes. Every effort will be employed to create modular machine components to reduce production and maintenance costs.

Goal 5. Develop specifications and documentation guidelines for demonstration and research software for manufacturing information system studies based on CAD/CAM Mini-Lab equipment.

Goal 6. Develop and test CAD/CAM demonstration and research software at various university sites.

Goal 7. Establish a CAD/CAM Mini-Lab software exchange program for sharing programs developed for the CAD/CAM Mini-Lab.

Goal 8. Explore transferability of principles, concepts, and software designs from the CAD/CAM Mini-Lab environment to full-sized CAD/CAM systems operating in a real-world production environment.

10. Work Accomplished with AFOSR Funding

The work accomplished to date with AFOSR funding will be reported in the following five categories: 1) miniature machine tools, 2) machine controller, 3) demonstration software, 4) interface development, and 5) integration and testing.

In accordance with the work plan shown in Figure 11 below, the project is on schedule. Tasks 1.0-4.0 were accomplished prior to the AFOSR Grant

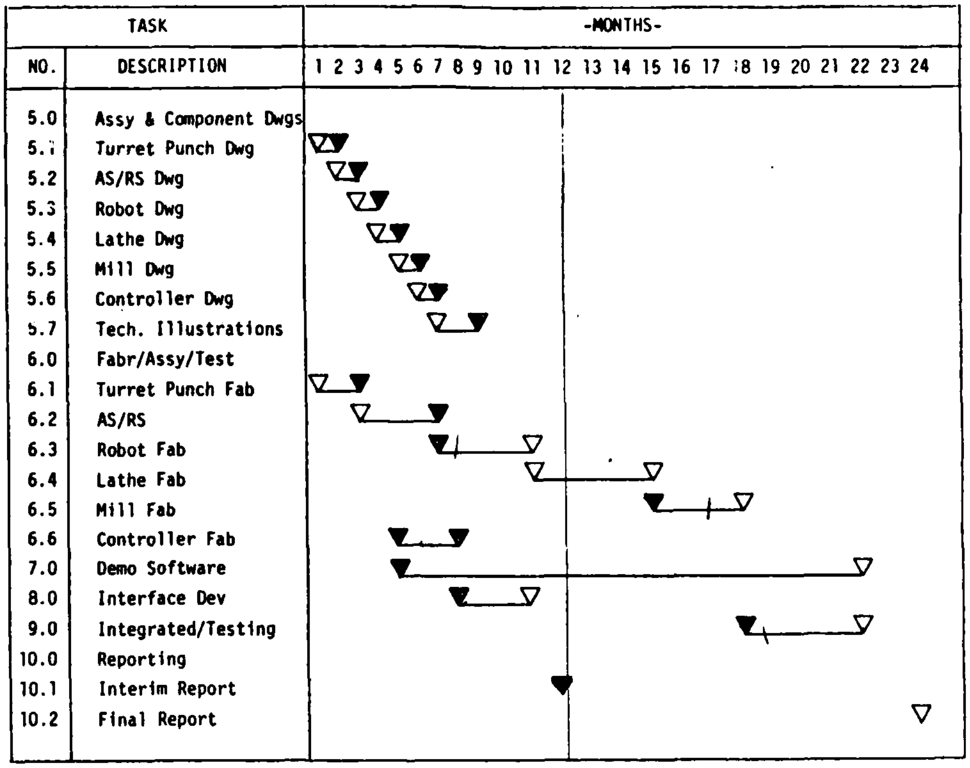


Figure 11

and included: 1.0) review existing full-sized CAD/CAM equipment and systems, 2.0) develop an overall architecture for the CAD/CAM Mini-Lab

including major hardware components (See Appendix A), 3.0) create high-level specifications for CAD/CAM hardware and software components (See Appendix B).

10.1 System Layout. The overall layout of the CAM Mini-Lab is shown in Figure 12. The equipment includes an IBM-PC for the graphics (CAD) function, an IBM-XT to serve the function of the host computer to schedule and manage the various machines, four (4) Apple II microcomputers, each of which is equipped with a Z-80 (Microsoft card) and three (3) 6-Axis controllers for the various machines. The fabrication machines include a lathe, mill, and turret punch. Equipment for materials handling include the automated storage and retrieval system (AS/RS) and the 5-axis robot. The robot will be used for machine loading, inspection, and assembly.

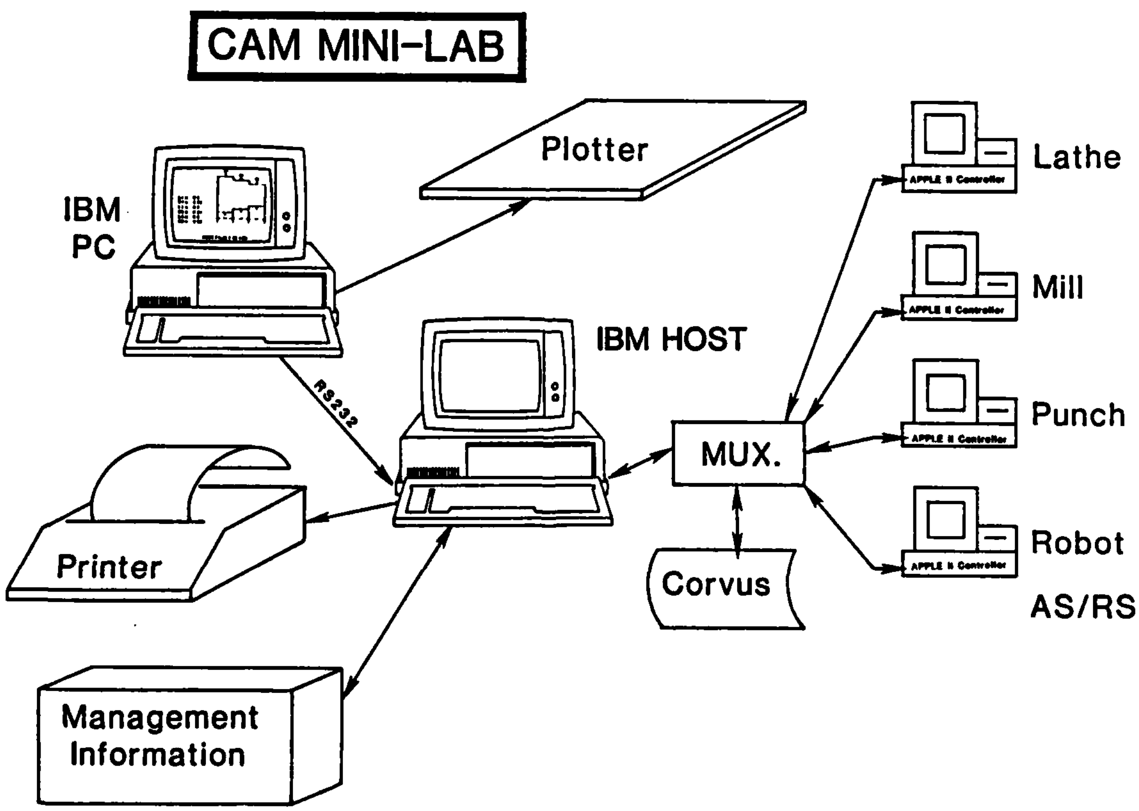


Figure 12

10.2 Information Flow. The information flow model is shown in Figure 13. The IBM-XT host computer will be used to down-load instructions to each of the Apple II/Z-80 machine controllers. The Apple II computers were selected at the time because of their low-cost and flexibility in accepting various cards such as the Z-80 softcard with its CP/M MBASIC software.

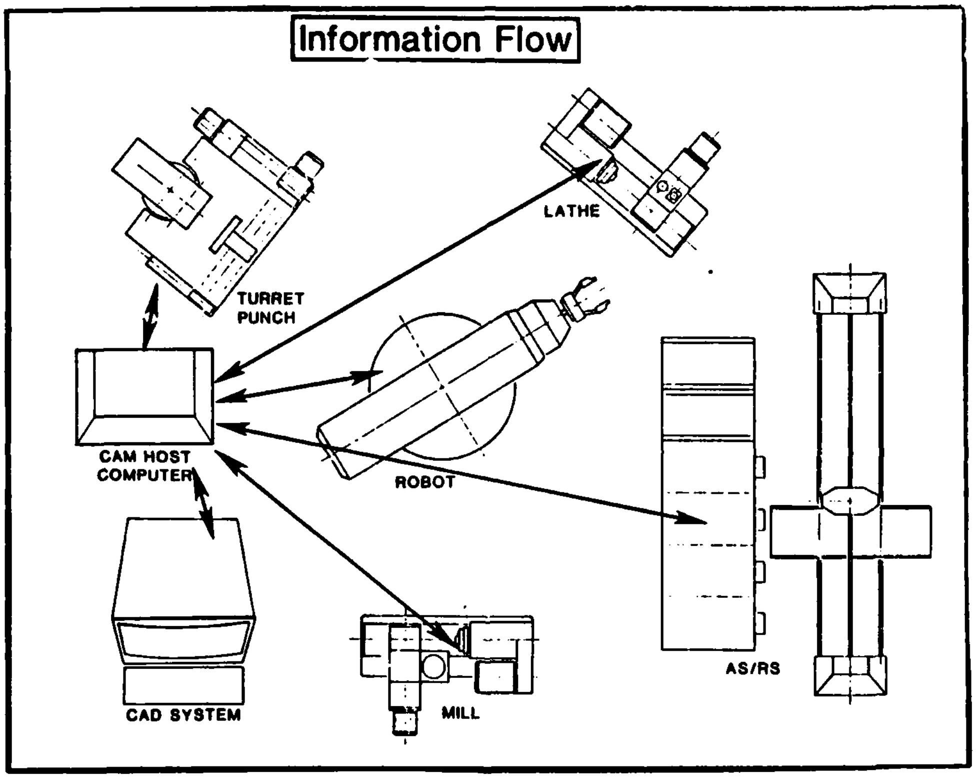


Figure 13

The initial concept, which is shown in Appendix A, called for a Tektronix 4050 graphics terminal and a MacSym-2 host computer. The availability of the low-cost and powerful IBM-PC and -XT microcomputers caused a change in configuration to the one shown. The cost of computer hardware for the new configuration is approximately one-fourth of that for the initial concept.

10.3 Material Flow. The material flow for the CAM cell layout is shown in Figure 14. Raw materials stored in the AS/RS will be retrieved under computer control, the inventory updated, and the robot will load one of the fabrication machines. The material will be processed to modify its basic shape or to impart selected form features. The finished piece will then be inspected and returned to the AS/RS where it will be stored, ready for assembly. When all pieces have been fabricated, they will be assembled according to the sequence dictated by the product explosion tree. Finished products are to be packaged and stored for marketing and delivery.

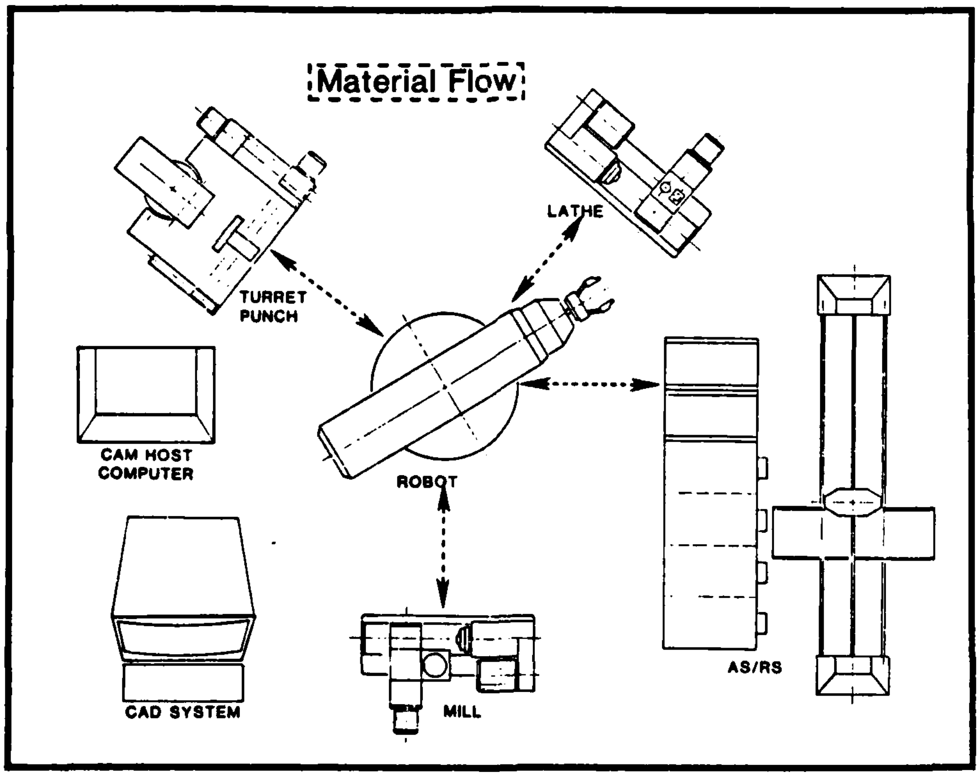


Figure 14

10.4 Turret Punch. (Task 5.1/6.1) The turret punch for sheet-like parts fabrication was designed and has also been produced during Phase I. The completed miniature machine is shown in Figures 15 and 16.

The machine has a travel of 11" and 5" in the X-axis and Y-axis respectively. It has been designed with an eight-station turret and a punching capacity of .020" in cardstock.

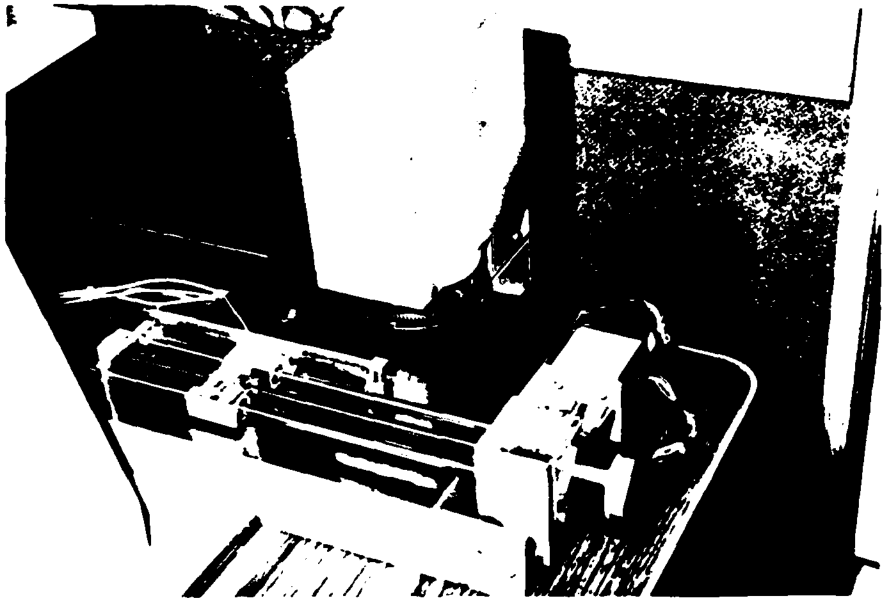


Figure 15. Turret Punch Assembled

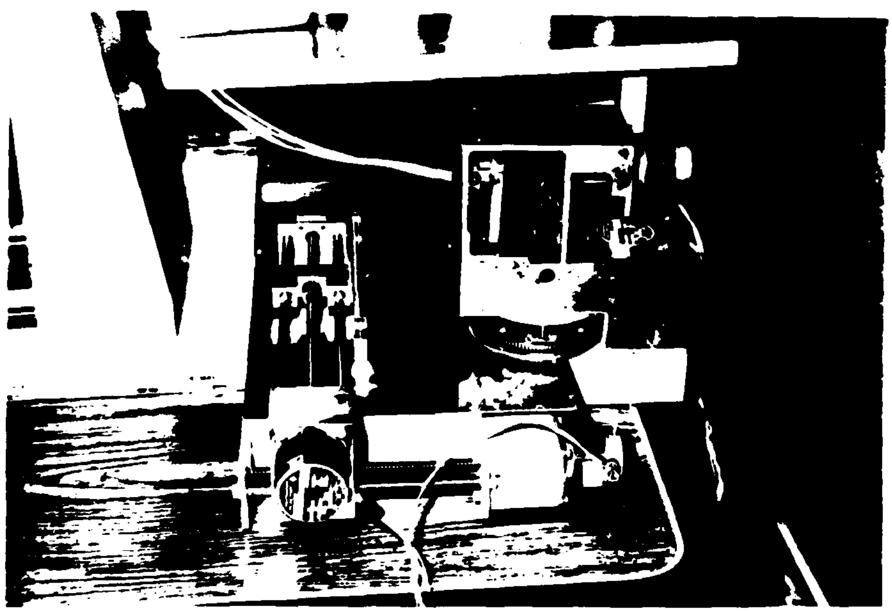


Figure 16. Turret Punch Inner Mechanism Showing Toggle and Eight-Station Turret

10.5 Automated Storage and Retrieval System. (AS/RS) The automated storage and retrieval system, shown in Figure 17 is approximately 55" long and 23" high. It is equipped with ball screws and three (3) stepper motor drives for positioning and bin retraction.

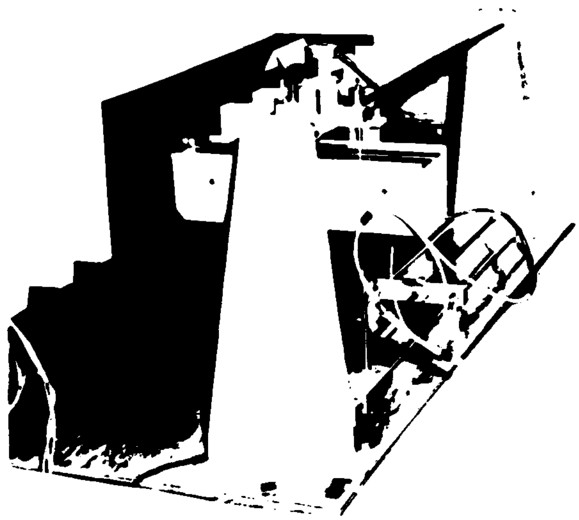


Figure 17. Miniature Automated Storage and Retrieval System (AS/RS)

There are 18 bins, Figure 18, which can be used for storage of raw materials, in-process inventory, finished goods, or tooling. Raw materials

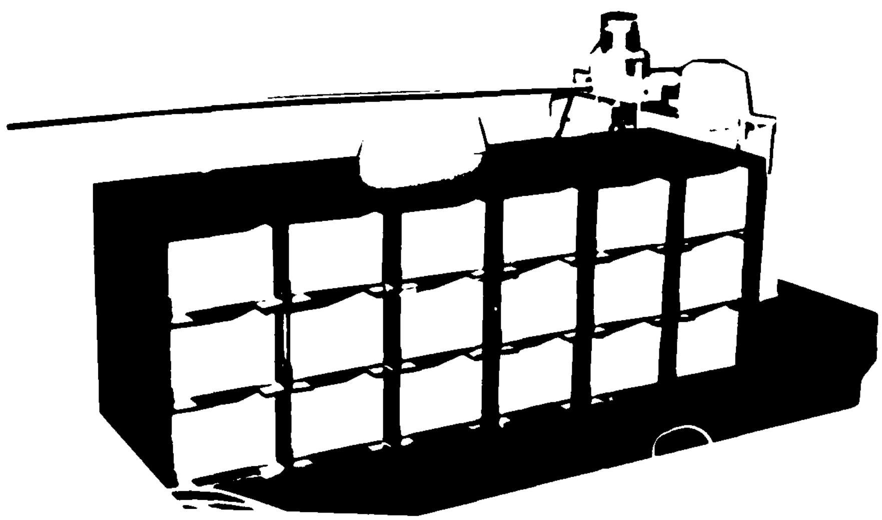


Figure 18. Storage Bin Layout (Rear)

include box-like, sheet, and rod stock. Box-like parts are staggered so that they may be gripped by the robot. Sheet stock will require that a vacuum gripper mechanism be developed. Rod stock are currently supported on an inclined plane so that they roll into position to be grasped by the robot.

Mechanical work on the AS/RS was performed mainly by Tim Ward with assistance by Vaughn Dearden. Equipment designer was Forest Blair who designed all of the equipment for the CAM Mini-Lab.

10.6 Robot. The robot is currently being fabricataed as shown by Figure 20. It will be a spherical envelope robot with 5 axes of motion. The robot is being designed with a 10 lb. capacity, and 15" of reach. Preliminary design analysis indicates that it should be capable of 0.005" repeatibility.

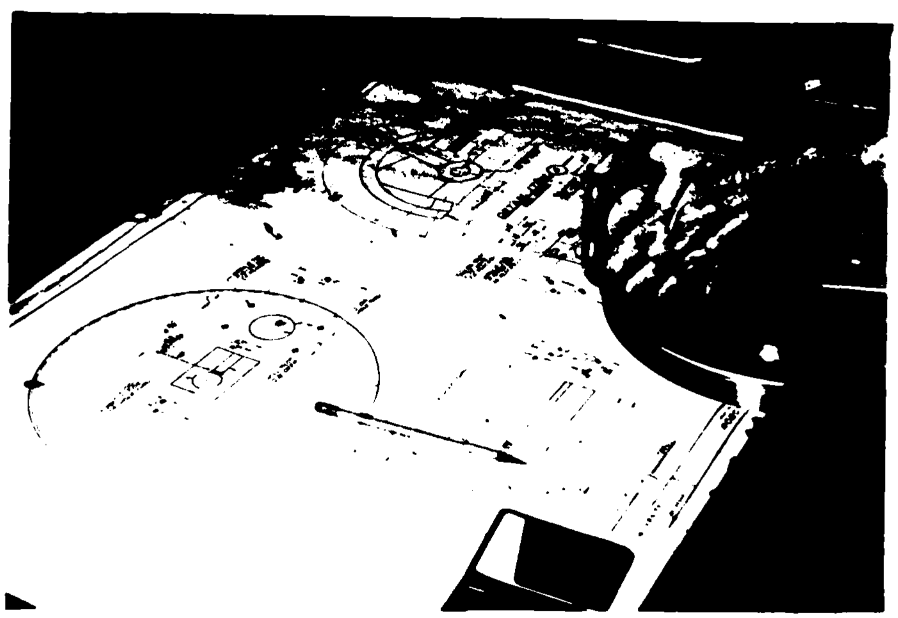


Figure 20. Base Fabrication for Robot

10.7 CNC Lathe. The CNC lathe (Fig. 19) is to have a turret with 4-6 tools and a self-opening chuck. The drive for the lathe is to be a variable speed DC drive. The lathe is to be equipped with an adaptive controller (A/C) to modify feeds, speeds, and depth of cut.

The turret is to be equipped with tools to perform turning, facing, grouping, chamfering, cut-off, and boring operations. The spindle encoder, to be used for adaptive control, will also be used to provide synchronization of spindle and carriage drive to permit threading.

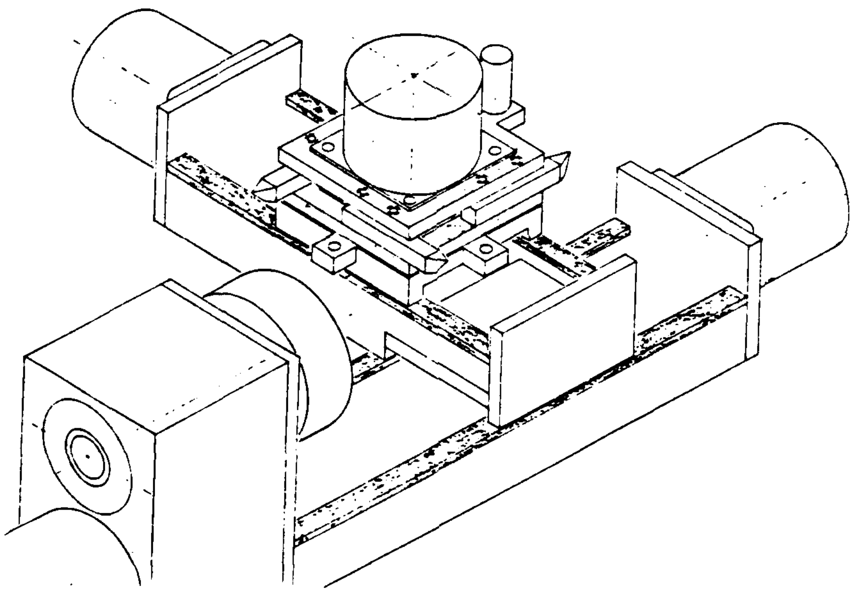


Figure 19. CNC Lathe

10.8 Polar Coordinate Mill. The polar coordinate mill (Fig. 21) represents an innovative, new approach to machine design. Most milling machines are constructed with a cortesian coordinate system. Since many surfaces now being machined are non-planar it requires that several axes move simultaneously. The polar coordinate mill design permits the design of a machine with 5-axis capabilities with only 4 drive motors. The new design,

which requires a new programming approach, is being funded jointly by the Technology Department and by Digital Equipment Company to provide a 3-D copy machine for industrial designers. A copy of the prototype machine will be incorporated in the CAM Mini-Lab. Vaughn Deaden is doing the major mechanical development on this project.

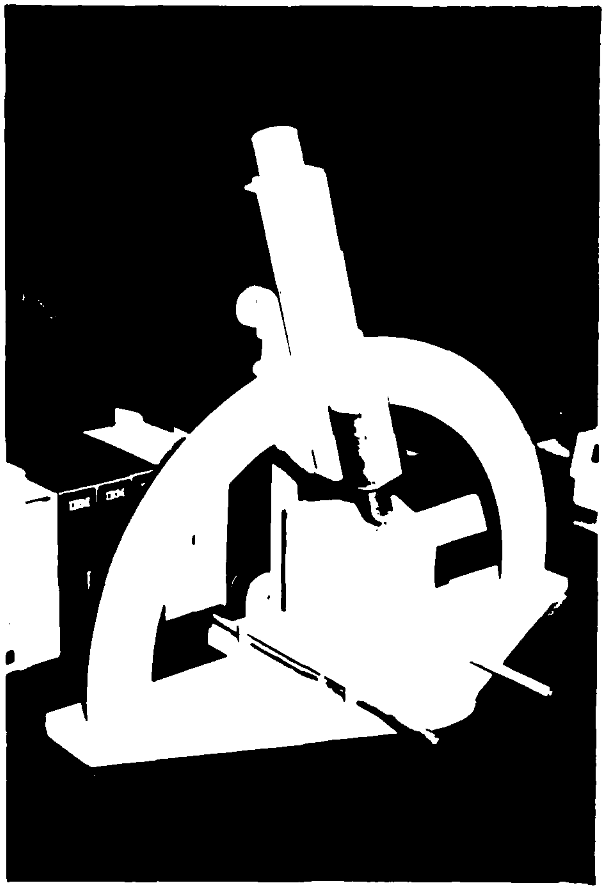


Figure 21. Polar Coordinate Mill

10.9 Controller. The controller for the CAM Mini-Lab consists of two basic components: 1) the microcomputer programming unit and 2) the stepper motor drivers and power supplies.

The Apple II/Z-80 microcomputer programming unit (Fig. 22) provides a keyboard and display for generating this cutting sequence for the various machine tools and the motion sequence for the robot manipulataor and AS/RS.

A 10 MB Corvus hard disk provides a buffer to down-load stored programs to the various machine controllers under the direction of the IBM-XT host computer.

Figure 22. Microcomputer Programming Unit

The stepper motor-driver and power supply (Fig. 23) is a custom designed unit which is capable of driving up to six Digital stepper motors simultaneously.

The controller was developed by Robotic Synergy, Inc., of Salt Lake City with the aid of Justin Redd.

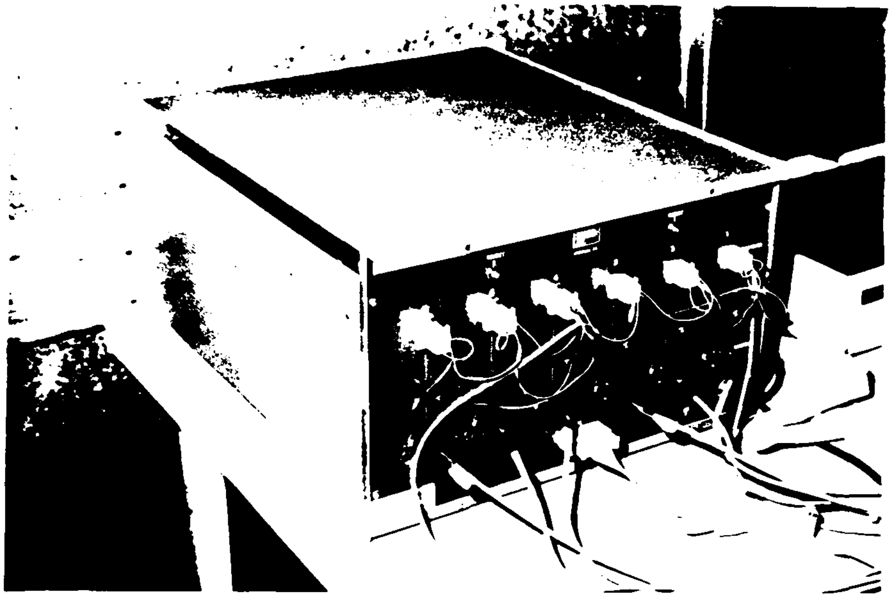


Figure 23. Stepper-Motor Drives and Power Supplies

10.10 Demo Software. Demonstration software developed to date has been designed to control the AS/RS, lathe, milling machine, and turret punch.

Much additional work needs to be done in this area, some of which is to be performed under the continuation grant and some under the proposed Phase II program.

Demonstration software has been developed by Paul Smith, Dave Jesperson, Brandt Redd, and Justin Redd.

10.11 Interface Development. Interface development has included creation of software to permit communication between the Apple II/Z-80 microcomputer programming units and the stepper-motor controller. It has also included the integration of an electronic switch to function as a multiplexing device between the IBM-XT host and the four Apple II programming units.

In operation, the IBM graphics system will be used for parametric design (Fig. 24). Next data will be transmitted over an RS-232 serial line to the host computer (Fig. 25) where process planning, scheduling, estimating, inventory, etc., will be performed. Data and instructions will then be transmitted to the Apple II programming units to control the various machines. Control data and programs for the Apple II programming units will be stored on a Corvus hard disc.

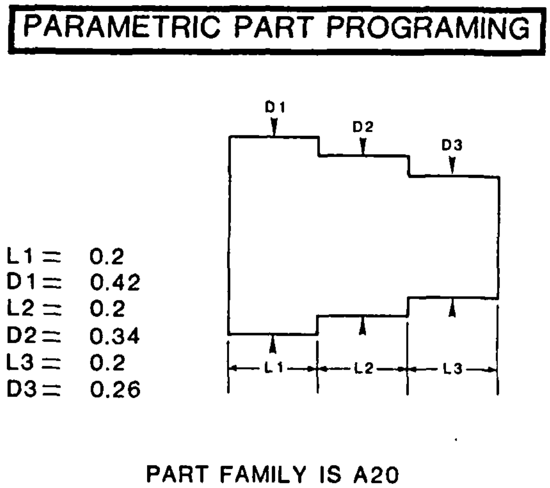


Figure 24

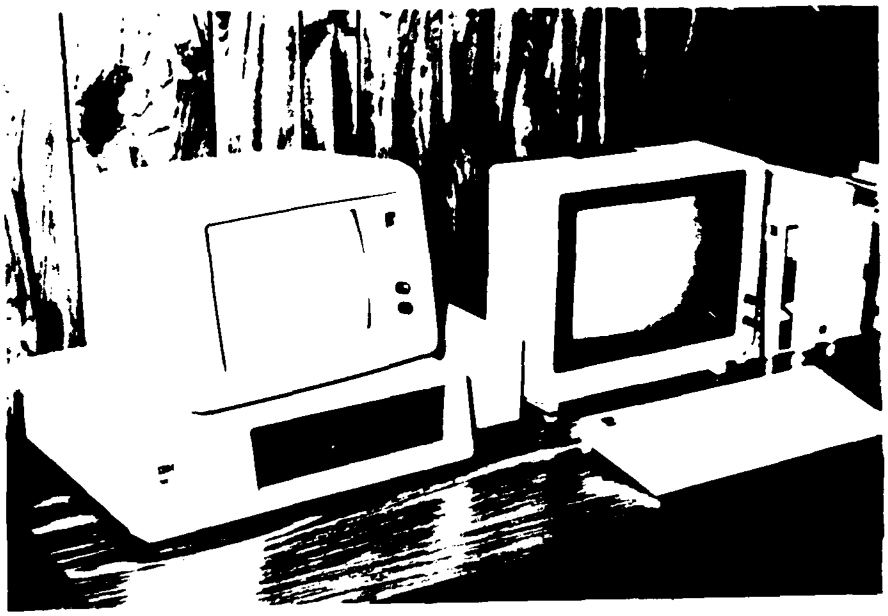


Figure 25. IBM Host Computer

Each Apple will be equipped with a bar-code reader (Fig. 26) to permit rapid recall of machine control programs, inventory tracking, or tool verification.

Interface development software has been developed primarily by Merrill Smart and Justin Redd.

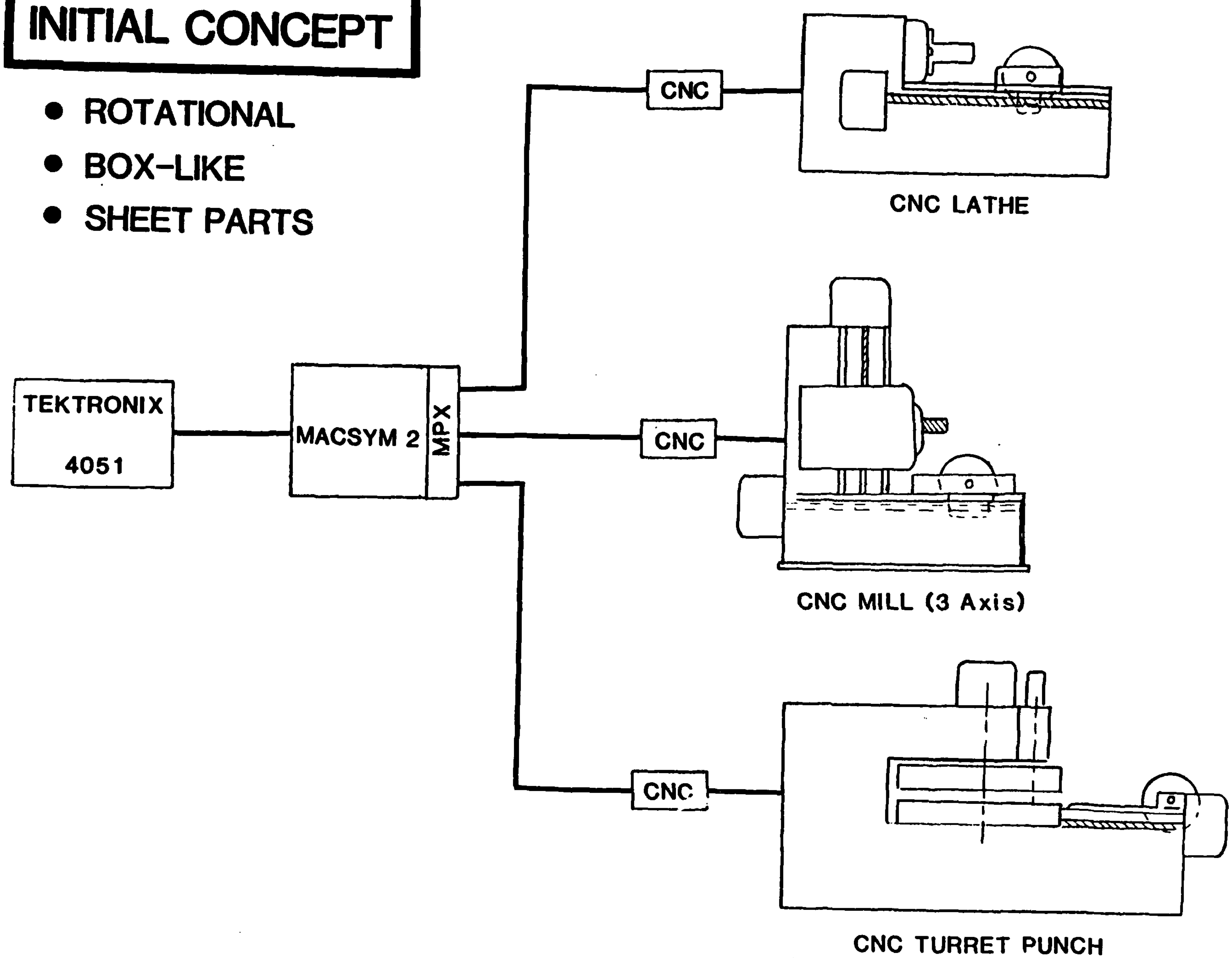
Figure 26. Bar-Code Reader for Bar Coded Parts

APPENDIX

APPENDIX A

INITIAL CONCEPT

- ROTATIONAL
- BOX-LIKE
- SHEET PARTS



SPECIFICATIONS -- CNC LATHE

- 2 in. swing x 6 in. length capacity
- 1/10 h.p. drive motor
- Spindle speeds, 0-2000 rpm
- Positioning rate, 0-50 in./min.
- Resolution .0005 in./step
- Materials: aluminum, brass, plastic, wood
- Spindle thread 5/8-11 unc
- Tools, 1/4 in. square shank

SPECIFICATIONS -- CNC MILL

- 4 in. cube capacity
- 1/10 h.p. drive motor
- Spindle speeds, 0-2000 RPM
- Positioning rate 0-50 in/min
- Resolution .0005 in/step
- Materials: Aluminum, brass, styrofoam, wood
- Spindle thread 5/8-11 unc
- 4-position indexable turret

SPECIFICATIONS -- CNC TURRET PUNCH

- Sheet size 4 in. x 8 in.
- Capacity 1/4 in. dia. x .020 in. card stock
- Positioning rate, 0-50 in./min.
- 4-position indexable turret
- Materials: paper card-stock

SPECIFICATIONS -- AUTOMATED STORAGE UNIT

- Bin capacity 2lbs.
- Bin size 4 in. x 4 in. x 8 in.
- Storage for: Rotational, box-like and sheet parts
- Traverse rate: 100 in./min.
- No. of bins: 18

SPECIFICATIONS -- MICRO-ROBOT

- Capacity: 1 lb.
- Range: 8 in. x 17 in.
- Positioning accuracy: $\pm .005$ in.
- Positioning rate: 200 in./min.
- No. axes: 5

SPECIFICATIONS -- CNC CONTROL UNIT

- 48-k Apple II CPU
- 5 in. monitor and controls
- CY512 stepper motor controller
- Rs-232 interface to host
- Single floppy disc drive

SPECIFICATIONS -- SOFTWARE

- Programming language: BASIC
- Structure: mainline and subroutine
- Utilize basic shape/form features
- Incorporate parametric design capability
- Provide family of parts N/C programming
- Architecture: hierarchal
- Usage: menu-driven

APPENDIX B

CONTINUATION PROPOSAL

14 July 1983

- Continuation Proposal -

For AFOSR Grant #82-0253

MANUFACTURING INFORMATION SYSTEM

Submitted to

Air Force Office of Scientific Research
Building 410, Room 223
Bolling Air Force Base
Washington, D.C. 20322 N.C.

July 14, 1983

Principal Investigators:
D.K. Allen, P.R. Smith, & M.J. Smart

Computer Aided Manufacturing Laboratory
Brigham Young University
Provo, Utah 84602

CONTINUATION RESEARCH PROPOSAL SUBMITTED TO THE

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

Proposed Amount $59,570

Proposed Effective Date Sept. 1, 1983

Proposed Duration 12 months

Title: MANUFACTURING INFORMATION SYSTEM

Principal Investigators: D. K. Allen, P. R. Smith, M. J. Smart

Address to which grant should be awarded:

RESEARCH DIVISION
BRIGHAM YOUNG UNIVERSITY
C-37 ASB
PROVO, UTAH 84602

Endorsements:

Principal Investigators	#1 D. K. Allen	#2 P. R. Smith	#3 M. J. Smart
Signature:	Dell K. Allen	Paul R. Smith	Merrill J. Smart
Title:	Professor	Research Associate	Associate Professor
Phone #:	(801) 378-3895	(801) 378-2293	(801) 378-3892
Date:		14 July 83	14 July 1983

Department Chairman: John J. Kunzler

Signature: John J. Kunzler
Title: Department Chairman
Date: 7/14/83

Dean:

Signature:
Title: Associate Dean, College of Engineering & Technology
Date: 7-14-83

Institutional Representative. Neal E. Lambert

Signature: Neal Lambert
Title: Associate Academic V.P.
Date: 15 July 1983

-ABSTRACT-

The size and cost of manufacturing equipment has made it extremely difficult to perform realistic modeling and simulation of the manufacturing process in university research laboratories. Likewise the size and cost factors, coupled with many uncontrolled variables of the production situation has even made it difficult to perform adequate manufacturing research in the industrial setting. Only the largest companies can afford manufacturing research laboratories; research results are often held proprietary and seldom find their way into the university classroom to aid in education and training of new manufacturing engineers.

It is the purpose for this continuation proposal to obtain a grant to continue the development of miniature prototype equipment suitable for use in an integrated CAD/CAM Laboratory. The equipment will be capable of actually performing production operations (e.g. drilling, milling, turning, punching, etc.) on metallic and non-metallic workpieces.

The integrated CAD/CAM Mini-Lab will integrate high resolution, computer graphics, parametric design, parametric N/C parts programmings, CNC machine control, automated storage and retrieval, with robotics materials handling.

The availability of miniature CAD/CAM laboratory equipment will provide the basis for intensive laboratory research on manufacturing information systems.

The proprosed research and development effort for the CAD/CAM Mini-Lab will be performed in three distinct phases. The first phase, lasting 2-years, will be devoted to prototype development and testing of the following miniature equipment (1) CNC Lathe, (2) CNC Mill, (3) CNC Turret Punch, (4) Storage and Retrieval System, (5) Micro-Robot, and (6) CNC Machine-Tool Control System. Demonstration software will also be developed for

integrating CAD/CAM graphics with the CNC Machine-Tool Control System. Phase two, one year, will be used for developing production models from the prototypes created during phase one, producing multiple copies of each piece of equipment and placing this equipment in a consortium of selected educational institutions. The planned phase three would be a one-year effort to develop extensive CAD/CAM software at institutions selected during phase two, concluding with a software exchange program. Software documentation standards would be provided for each institution to insure useability, transportability, and maintainability. It is expected that a vast amount of relevant manufacturing information will be collected and procedures developed from CAD/CAM Mini-Lab which will be directly applicable to a full-sized manufacturing plant operation. It is anticipated that programs developed by the educational consortium will include expansion of parametric design and programming applications, testing and evaluation of process control algorithms, evaluation and testing of programming procedures, experimentation with CAD/CAM Data Base design, development and utilization of group technology principles, shop floor scheduling and control, communication and distributed processing, etc., etc.

TABLE OF CONTENTS

MANUFACTURING INFORMATION SYSTEM

1. INTRODUCTION

1.1. BACKGROUND In tracing the history of machine tools, it is interesting to note that machine-tools have developed over the past 200 years from relatively small mechanical devices with manual control to large, complex systems often containing electrical, electronic, hydraulic, and mechanical actuating and control subsystems.

The need for increased machine-tool complexity has arisen from increased sophistication of the products being designed and manufactured. Today, many consumer and user products contain electronic and microprocessor sinsing and control systems. Transportation and weapons systems contain the ultimate in complex configurations which must be designed, produced, and tested.

The size, complexity and cost of modern manufacturing equipment and systems is conderable; this has made it extremely difficult for universities to acquire modern manufacturing equipment for either education or for manufacturing research. Manufacturing research is essential in order to develop realistic process modeling and simulation studies. Education is essential if graduating engineers and technologists are to be aware of the principles governing optimum utilization of advanced manufacturing systems.

The size and cost factors of manufacturing systems, with many uncontrolled variables in the production situation has even made it difficult to perform adequate manufacturing research in the industrial setting. Only the largest companies can usually afford manufacturing research laboratories; research results are often held proprietary and seldom find their way into the university classroom to aid in the education and training of new manufacturing engineers.

1.2. NEED There is a current and pressing need to develop scaled-down and somewhat less sophisticated and less costly manufacturing equipment and systems for university level teaching and research purposes. The equipment must be capable of performing small-scale production operations and must be capable of being integrated into a system so that such things as data bases, data flows, control and scheduling, cutting forces, tool life, etc., may be realistically studied.

Once the hardware need is met then the next need is to model, simulate and test the manufacturing system. Modeling of an actual system can greatly facilitate testing of the computer simulation models. In many of the manufacturing simulation studies being carried out today, it is difficult to test the simulation model to insure its validity. The CAD/CAM Mini-Lab would solve this problem.

1.3. MISSION AND GOALS The mission of the manufacturing information system is to develop and test scaled-down manufacturing equipment and systems as a basis for manufacturing education, manufacturing research, and manufacturing simulation studies. Goals for accomplishing the stated mission include the following:

Goal 1. Design and develop prototype production equipment for processing and handling of box-like, sheet, and rotational parts made from metallic and non-metallic materials.

Goal 2. Design and develop a small, microprocessor-based, computer numerical control (CNC) system for controlling processing and handling equipment.

Goal 3. Develop and test the CAD/CAM interface between a small computer graphics display device and the CNC processing and handling system.

Goal 4. Develop production versions of the prototype hardware and produce a number of units for installation at selected universities who

are interested and capable of testing the equipment in the education and research modes. Every effort will be employed to create modular machine components to reduce production and maintenance costs.

Goal 5. Develop specifications and documentation guidelines for demonstration and research software for manufacturing information system studies based on CAD/CAM Mini-Lab equipment.

Goal 6. Develop and test CAD/CAM demonstration and research software at various university sites.

Goal 7. Establish a CAD/CAM Mini-Lab software exchange program for sharing programs developed for the CAD/CAM Mini-Lab.

Goal 8. Explore transferability of principles, concepts, and software designs from the CAD/CAM Mini-Lab environment to full-sized CAD/CAM systems operating in a real-world production environment.

During Phase I of the proposed grant program, only goals 1-3 will be addressed. Individual tasks for accomplishing each of the three stated goals are contained in Paragraph 1.4. Similar tasks will be developed for each of the other defined goals to insure that they can be met within the stated time and budget constraints.

1.4. METHOD OF PROCEDURE The method of procedure for this program has pretty well been established by preliminary R & D efforts funded by the CAM Laboratory at Brigham Young University.

This procedure has included accomplishing the following tasks:

1. Review existing full-sized CAD/CAM equipment and systems.
2. Develop an overall architecture for this CAD/CAM Mini-Lab including major hardware components.
3. Create high-level specifications for CAD/CAM hardware and software components.

4. Develop hardware mockups.
5. Develop detailed assembly and component drawings for each piece of equipment to be fabricated.
6. Fabricate, assemble and test equipment.
7. Design, code and test software.
8. Develop electronic interface between CAD and CAM hardware components.

A miniature Japanese camera lathe has been retrofitted with ball-screws and stepper motors. This CNC lathe is controlled by the MacSym computer for generating N/C cutter paths. Various families of parts can now be provided from data transmitted from the graphics system. No paper work is involved. All data is transmitted directly. A fiber-optic RS-232 link has been used for communication between the host computer and the lathe stepper motor driver logic.

A small EDM electrode drilling machine has also been retrofitted with ball-screws to provide a prototype for a 3-axis milling machine. This machine has also been equipped with a special table for circuit-board drilling.

A small 5-axis Microbot has also been acquired for the CAD/CAM Mini-Lab. This robot is commercially available, but has a number of failings and these include inability to accurately return to a home-position, and general lack of rigidity. The system is currently operated with a TRS-80 microcomputer.

1.5 <u>ACCOMPLISHMENTS TO DATE</u> Tasks No. 1 - 4 have already been completed as shown in the attached photograph (Attachment A). Task 5 is currently underway and detailed drawings have been completed for two of the six anticipated miniature machine tools (automated storage and retrieval system, and turret punch) and a miniature 5-axis robot is now being designed. Task 6 has been essentially completed for the miniature 8-station turret

punch.

A special stepper-motor driver card has also been developed for use with the Apple II computer numerical control (CNC) System and is now being tested.

Preliminary work has been accomplished in successfully connecting a Tektronix 4051 computer graphics system to a Macsym process control micro-computer which will act as the host for the Apple II/CNC machine controllers. Parametric design and part programming routines have been written and tested.

1.6 PLANS Plans for the near future include continuation towards the mission, goals and tasks stated earlier. Additional finding will accelerate progress and will permit: (1) upgrading of the Tektronix graphics system to the 4052 which is approximately ten times faster and which has improved graphics routines, (2) exploring the possibility of utilizing new Winchester disc technology with the Tektronix 4052, (3) utilizing the Corvus 10-MB Winchester disc as a shared device for the Apple II/CNC controllers, and (4) exploring the possibility of utilizing a lower cost Macsym 2 controller as the interface (host) computer, between the Tektronix 4052 and Apple II/CNC controllers. Alternately, we will be exploring the possibility of using another Apple II Computer as the Host for scheduling purposes. (This latter option will require writing or acquiring a real-time operating system for the Apple II.)

2. IMPACT ON MANUFACTURING SCIENCE AND TECHNOLOGY

2.1 ANTICIPATED RESULTS While the full-sized CAD/CAM laboratories at Brigham Young University have attracted considerable attention the most impressive thing to many visitors has been our work with the CAD/CAM Mini-Laboratory. Already two theses have been completed using the Mini-Lab by students who are enrolled in the M.S. Degree Program in Computer Aided

Manufacturing; and three additional theses are in progress.

In view of the enthusiastic response we have had from visitors who have seen our CAD/CAM Mini-Lab and very positive response we have had with graduate research projects we believe the proposed project can have a rapid, and far-reaching impact on improving manufacturing technology and developing a manufacturing science. One other project which is currently underway at the university and which can have a synergistic effect with the CAD/CAM Mini-Lab is the development of manufacturing training materials. The project, funded by an industrial consortium, is developing some 250 educational modules for conventional and advanced production processes. The project is expected to last 42-months and cost $1.2 million dollars. Deliverables will include transparency masters, student handouts, 35mm slides, video-tapes, and eventually an interactive videodisc delivery system. By vote of the consortium members, we will branch out to include CAD/CAM activities as soon as the planned modules are completed.

There is a natural interaction between the training materials described above and the CAD/CAM Mini-Lab discussed in this proposal.

2.2 SUPPORT FOR AGENCY It is our belief that successful completion of the two projects just described plus our own demonstrated and successful completion of generative process planning using DCLASS, can have greater impact on manufacturing science and technology than any other combined activity.

The stated mission of the CAM Laboratory is "to aid in increasing industrial productivity through the application of advanced technology". Participation by the Air Force Office of Scientific Research can aid in accelerating the development work and in dissemination to qualified educators and researchers.

One of the five major program areas identified by the Air Force Office of Scientific Research is that of Manufacturing Science. Like any science Manufacturing Science must be based upon theory, observation, experimentation, modeling, simulation, etc. The proposed project directly supports the Manufacturing Science program by making available suitable equipment for laboratory research.

3. UNIQUENESS OF PROPOSAL The AFOSR is probably in the best position to judge the uniqueness of this proposal. We know of no other investigators who have such a comprehensive plan unless they have received it from us. We are aware of projects which use Erector-set equipment for simulation of transfer line machining, and peg-board type storage and retrieval systems; we are also aware of work that has been done with miniature computer controlled milling machines, and in fact some are commercially available at nearly the cost of full-sized equipment, but we have yet to see any work relative to an integrated miniature CAD/CAM System which can actually produce parts.

4. QUALIFICATIONS OF PERSONNEL All personnel selected for this project have already been involved and have demonstrated their proficiency. Resumes are attached.

Briefly, qualifications and duties are as follows:

Principal Investigators:

1. D. K. Allen, Director of CAM Laboratory, Professor of Manufacturing Technology, Originator of concept for CAD/CAM Mini-Lab.
2. P. R. Smith, Research Associate, CAD/CAM Mini-Lab project manager, teaches course in Group Technology, has been involved with Educational Module Development Project.
3. M. J. Smart, Associate Professor of Electronics, Teacher

course work in Computer Technology, broad industrial experience; has been involved with assembly language programming of CY 512 for process control.

Technician/Design Consultant:

1. V. L. Dearden, Prototype Development Technician, extensive industrial experience, tool-die and prototype development.
2. F. Blair, Mechanical Designer, Inventor, Technical Illustrator.

5. FACILITIES AVAILABLE There are presently some 19 machine shops and electronic shops on the BYU campus including a large research shop. Equipment is available for conventional and CNC production. Modern laboratory facilities are also available for sheetmetal forming, plastic molding, casting, welding, finishing, painting, heat-treating, and inspection.

6. COST OF SPECIAL EQUIPMENT Following is a list of special equipment which will be required for design and testing of the prototype production system.

		TOTAL
5 ea	Apple II 40-K Microcomputers @ $1075 ea	5,375
6 ea	15 ft Cable and Interface Card @ $205 ea	1,230
1 ea	Corvus 10-MB Winchester Disc	4,370
1 ea	Host Multiplexer for Corvus Disc	735
1 ea	Mirror Backup/Recorder	840
1 ea	Tektronix 4052 graphic display	10,950
	with option 24, 64K Bytes memory	2,000
	with option 01 Data Communication Interface	1,500
	TOTAL	$27,000

Equipment which is already on hand and being used currently for the Mini-Lab includes: 1-Apple II/Display Micro Computer, 1-Macsym II Micro-Computer, 1-Tektronix 4051 (early version to be upgraded), 1-TRS-80 (Radio

Shack) Micro Computer, 1-Microbot-5 Miniature Robot, 1-Toyo Camera Making Lathe, 1-Horizontal Drilling/Milling Machine.

The special equipment acquired with this grant will be used solely for the implementation of the prototype CAD/CAM Mini-Lab project. At the completion of the project, title to equipment used for prototype development will be conveyed to Brigham Young University.

7. TIME SCHEDULE

7.1. TOTAL DEVELOPMENT TIME The time schedule for the three development phases is as follows: Phase I, prototype development (this proposal) 24-months; Phase II, prototype production, software specifications and institution selection, 12-months; Phase III, software development and software exchange, 12-months. Total development time: 48 months.

7.2 TIME SCHEDULE, PHASE I The time schedule for Phase I of the project is 24-months. A detail of the tasks to be completed is shown on Figure 1.

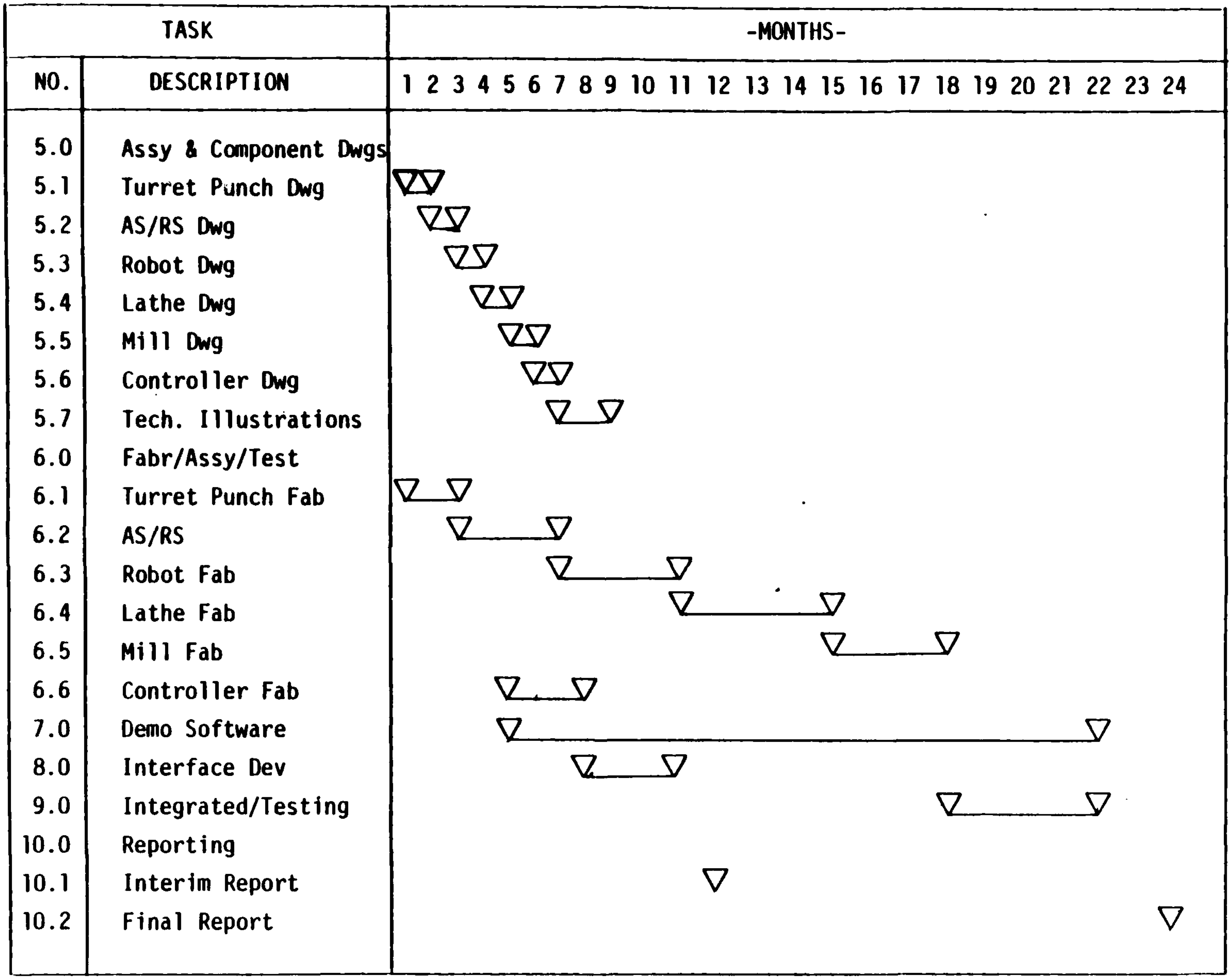
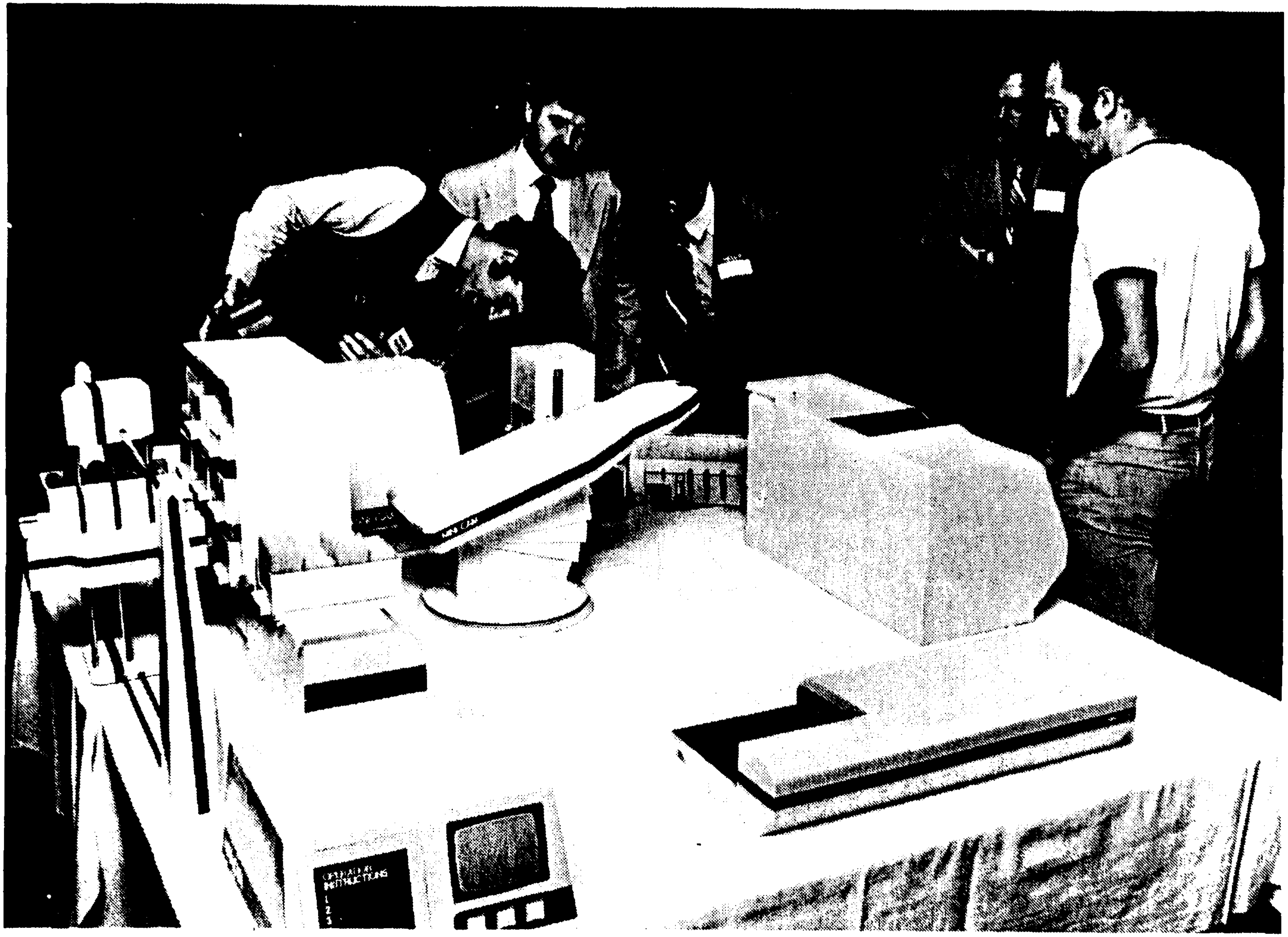

TASK
-MONTHS-
NO.
DESCRIPTION
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
5.0 Assy & Component Dwgs
5.1 Turret Punch Dwg
5.2 AS/RS Dwg
5.3 Robot Dwg
5.4 Lathe Dwg
5.5 Mill Dwg
5.6 Controller Dwg
5.7 Tech. Illustrations
6.0 Fabr/Assy/Test
6.1 Turret Punch Fab
6.2 AS/RS
6.3 Robot Fab
6.4 Lathe Fab
6.5 Mill Fab
6.6 Controller Fab
7.0 Demo Software
8.0 Interface Dev
9.0 Integrated/Testing
10.0 Reporting
10.1 Interim Report
10.2 Final Report

Figure 1

ATTACHMENT A:



ATTACHMENT A: Photograph of CAM Mini-Lab Mockup, with (clockwise from left) Material Handling System, Robot, CNC Mill, CNC Lathe, Laser Router (Turret Punch) and Control Stati

ATTACHMENT B:

8. <u>BUDGET</u> The revised budget for 1983-84 (2nd year) is shown below, along with the first year and total budget.

<u>Wages and Salaries</u>:

	1st YR (1982-83)	2nd YR (1983-84)	TOTAL
Principal Investigator No. 1 D. K. Allen (5% F.W./SU.-20% 2nd Yr.)	1,800	3,500	5,300
Principal Investigator No. 2 P. R. Smith (25%)	5,000	6,000	11,000
Principal Investigator No. 3 M. J. Smart (100% SP/SU)	9,000	5,000	14,000
Research Technician V. L. Dearden (25%)	9,000	5,000	14,000
Part-time Students	1,200	15,000	16,200
TOTAL WAGES & SALARIES	$26,000	$34,500	$60,500
Fringe Benefit (12% of W&S)	3,120	3,900	7,020
Travel	800	800	1,600
Supplies	7,000	3,000	10,000
*Consultant (1) F. Blair	10,000	-	10,000
Publication/Telephone/Postage	1,000	500	1,500
TOTAL DIRECT COSTS	$47,920	$42,700	$90,620
Indirect Costs (39.5% of Direct)	16,700	16,870	33,570
Capital Equipment	27,000	-	27,000
PROGRAM TOTAL	$91,690	$59,570	$151,260

*(1) The consultant, Mr. Blair is an experienced designer and technical illustrator who has already developed assembly and detail drawings for some of the CAM Mini-Lab. He is giving a special rate to us of only $10.00/hour. We do not believe it is possible to match this rate and quality of work by any other method.

RESUME

January 1981

NAME: Dell K. Allen

PERSONAL DATA: Age 49, married to Wanda Israelsen, 8 children

HOME ADDRESS: 195 South Inglewood Drive, Orem, Utah 84057
Home phone: (801) 225-3735

EMPLOYMENT: Brigham Young University
435 CB
Provo, Utah 84602
Phone: (801) 378-3895

TITLE: Director CAM Software Laboratory; Professor Manufacturing Engineering Technology; Certified Manufacturing Engineer; Reg. Prof. Engineer.

EDUCATION: Ed.D. Industrial Education, Utah State Univeristy, Logan, Utah, with minor in Manufacturing Engineering and Industrial Psychology, 1973.

M.S. Industrial Education, Brigham Young University, Provo, Utah. Supporting course work in computer science and statistics, 1966.

B.S. Manufacturing Engineering (formerly Tool Engineering) Utah State University, Logan, Utah, 1954.

Metallurgical Engineering graduate work at Illinois Institute of Technology, Chicago, Illinois; 1954-55.

TEACHING EXPERIENCE: 1975 - Present - Computer-Aided Manufacturing Laboratory; Member of Graduate Faculty.

1960 - 1975 - Program Supervisor, Manufacturing Technology at Brigham Young University. Development and teaching of courses in Computer-Aided Manufacturing, Manufacturing Process Planning and Estimating, Advanced Tooling Methods, Automation N/C, Cast Metal Process, Experimental Machining; Research in Industrial Process Adaptive Control, Sensor Development; and Computer Assisted Manufacturing Planning.

INDUSTRIAL EXPERIENCE: 1977 - Summer - Research Engineer, Boeing Commercial Airplane Co., Seattle, Washington. Implemented and tested computer information system for classification & coding, material selection and generative process planning. Reviewed classification & coding system with emphasis on interfacing with production systems.

1975 - Summer - Mechanical Engineer, Metrology section, Lawrence Livermore Laboratory, Livermore, California. 1) Directed berryllium machining investigation under Air Force/Honeywell contract; 2) Process documentation for diamond turning of optical surfaces on UV telescope condensor lens; 3) developed taxonomy of engineering materials and material/process selection algorithms.

1959 - 1960 - Manufacturing Process Engineer, EIMCO Corporation, Salt Lake City, Utah. Responsible engineer for N/C programming and equipment start up including development of tooling, gages, program and tape preparation and verification.

1955 - Summer Tool Engineer, EIMCO Corporation, Salt Lake City, Utah. Responsible for design of large milling fixtures for machining cast steel tractor housing.

1954 - 1955 Research Assistant, Illinois Institute of Technology, Chicago, Illinois. Designed and constructed apparatus for: automatic zone-refining of ultrapure aluminum, constant velocity stage for x-ray diffraction, powder metal compacting, sintering, and cold-rolling of high-temperature aluminum alloys.

1954 - Summer Tool Designer, EIMCO Corporation, Salt Lake City, Utah. Design of special tooling, boring bars, flating adaptors, tooling standards, and machinability data.

CONSULTING WORK: Manufacturing and educational consulting with many local and national organizations. Included are development of curriculum and accreditation guidelines for Manufacturing Technology; group technology assessment; prototype production of parts by means of numerical control and electrical discharge machining techniques; development of adaptive control equipment and industrial process sensors; design of 75-ton and 200-ton multipurpose processing and testing machines.

ORGANIZATION MEMBERSHIPS:
Computer-Aided Manufacturing, International, Incorporated. (formerly Chairman, CAM-I Standards Committee)
Phi Kappa Phi. (Honorary Scholastic)
Sigma Tau. (Honorary Engineer)
Society of Manufacturing Engineers. (formerly on National Education Committee)
American Society of Engineering Education. (formerly on Board of Directors)
American Society for Metals. (member)

HONORS AND AWARDS:
Distinguished College Faculty Member - 1980 - College of Engineering Sciences & Technology, Brigham Young University
CAM-I Ray J. Spies Education Award 1980, Cannes, France
SME International Education Award - 1975
Educational Achievement Award - 1971 (Society of Manufacturing Engineers, Region VII - Western States)
Engineering Merit Award - 1971 (San Fernando Valley Engineers' Council)
Listed in Outstanding Educators of America - 1970
NSF Faculty Research Fellowship - 1968
Lasalle Steel Company Research Fellowship - 1954-55
Distinguished Engineering Achievement Award - 1979, National Society of Professional Engineers, California

PUBLICATIONS:

Classification and Coding Monographs on the following subjects:

1. Part Family Classification, Monograph #3, August 1979.
2. Engineering Material Classification, Monograph #4, Jan. 19[illegible]
3. Fabrication Process Classification, Monograph #5, Jan. 198[illegible]
4. Equipment Classification, Monograph #6, Jan. 1980.
5. Tooling Classification, Monograph #7, Jan. 1980.

Printed and distributed by the CAM Software Lab, BYU, Provo, Utah.

"Information Systems for Computer Aided Manufacturing", (with Ronald P. Millett), CAM-I International Spring Seminar, April 19-21, 1977, Arlington, Texas.

"Impediments to Implementation of the CAM-I Long Range Plan", CAM-I International Spring Seminar, April 19-21, 1977, Arlington, Texas.

"Computer Aided Manufacturing at Brigham Young University, 1962-1977," CAM-I Annual Meeting, November 9-11, 1976, Dallas, Texas.

"Glossary of Computer Aided Manufacturing Terms", (ed.) with Robert C. Read, Pub. by Computer Aided Manufacturing International, Inc., 611 Ryan Plaza, Arlington, Texas, 76012, 1976.

"Training Engineers for Interdisciplinary Planning and Communication", ASEE Frontiers in Engineering Education, Atlanta, Georgia, Oct. 20-24, 1975.

"Systems Approach to Data Base Design for Computer-Aided Manufacturing", International CAM Seminar, Bournemouth, England, May 1, 1975.

"Performance Objectives--The Common Data Base for Manufacturing Education", paper presented at the SME Engineering/Technology Forum, Cobo Hall, Detroit, Michigan, April 8-9, 1975.

"Implications for Manufacturing Process Taxonomy in Process Selection", presented at the CAM-I Inc. International Congress on Computer-Aided Manufacturing, Hamilton, Ontario, Canada on May 14, 1974. Printed in proceedings of the meeting.

"Position Paper for Consideration by the CAM-I Standards Committee", Presented to the Standards Committee, CAM-I Inc., Denver, Colorado, July 30, 1974.

"Standards Committee Progress Report--1974. Presented to the membership, CAM-I Inc., at the Third Annual Meeting, Arlington, Texas. November 11-14, 1974.

"Industrial Process Adaptive Control (IPAC)" Paper presented at the Second Annual Meeting CAM-I Inc., November 12-16, 1973.

"A Report of CAD/CAM Activities at Brigham Young University 1964-73." Presented at the Second Annual Meeting CAM-I Inc., Arlington, Texas, November 12-16, 1973.

"Curriculum Performance Objectives for Manufacturing Engineering Technology", Doctoral Dissertation, Utah State University, Logan, Utah, June 1973.

"Metallurgy and Materials Science Laboratory Manual," (K.S. Mortensen, Co-author), American Technical Society, Chicago, IL. 1973.

"A Decade with Engineering Technology Education", paper No. 1620, presented at the annual meeting of the American Society of Engineering Education, Lubbock, Texas, June 1972.

"Adaptive Control Study Offered at BYU", Modern Machinery and Steel World, Vol. 61, No. 11, November 1970., p. 14-15.

Metallurgy Theory and Practice, Textbook, American Technical Society, Chicago, Illinois, 1969.

"Design of Seventy-Five Ton Hydraulic Multi-Purpose Laboratory Press for Testing and Processing of Manufacturing Materials", M.S. Thesis, Brigham Young University, Provo, Utah, 1966.

"Changing Processes Demand Change in Educational Approach", School Shop, Vol. XXV, No. 5, January 1966, pages 19-21.

"Needed Now--Manufacturing Engineering Education", The Tool and Manufacturing Engineer, Vol. 54, No. 1, January 1965, pp. 43-46.

Laboratory Manual for Experimental Metal-Cutting and Machine Tool Performance, Brigham Young University Press, 1965.

RESEARCH PROJECTS: Development of Computer-Aided Manufacturing Laboratory, funded by the Research Division, Brigham Young University, 1975-76.

Computer-Aided Manufacturing Planning (CAMP) System, funded by the Research Division, Brigham Young University, 1971-72.

Industrial Process Adaptive Control (IPAC). On-line machinability research, funded by the Research Division, Brigham Young University, Provo, Utah, 1970-72.

Individualized Laboratory Instruction Using the Audio Cassette, funded by BYU Instructional Development Grant, 1969-71.

Development of a 75-ton multipurpose hydraulic laboratory press and sixteen accessory attachments, BYU Research Grant, 1963-66.

Investigation of vibrations in metal boring operations, partially funded by Endevco Corporation, 1965.

Design and development of metal-cutting dynamometers for turning, milling, and grinding, funded by BYU Technology Dept., 1964.

Development of a calorimeter for investigation of the specific energy of metal removal during drilling operations, funded by Technology Department, BYU, 1961-62.

Design and construction of a zone-refining apparatus for preparation of ultra-pure metals, funded by Illinois Institute of Technology, Chicago, Illinois, 1955.

Design of a mold for preparation of artificial arteries, privately funded, 1954.

OTHER: Member, ad hoc committee Guidelines Committee of SME for Preparing ECPD Accreditation Guidelines for baccalaureate and associate curricula in Manufacturing Engineering Technology 1974-75.

Chairman, First International Computer-Aided Manufacturing Standards Workshop, February 4-5, 1975. Brigham Young University, Provo, Utah.

Member, ASEE (American Society for Engineering Education) Ethics Committee, 1973.

Member ECPD (Engineering Council for Professional Development Ad-Hoc Visiting Committee, Industrial and Manufacturing Engineering Technology, 1971-.

Chairman, Steering Committee, Manufacturing Technology forum sponsored by the Society of Manufacturing Engineers, Dearborn, Michigan November 15-16, 1971.

Consultant on Curriculum Development for Product Engineering curriculum, Western Electric Company, Corporate Education Center, 1972.

Host and participant, Industry-University Conference on Productivity Improvement, Brigham Young University, March 1, 2, and 3, 1978 in conjunction with the National Center for Productivity and Quality of Working Life.

RESUME

MERRILL J. SMART

Associate Professor of Technology
and
Program Supervisor for Electronics Technology
Brigham Young University
Provo, Utah 84602

Phone: 378-6307

HOME ADDRESS:	115 North 1170 East Springville, Utah 84663 (801) 489-6488
PERSONAL DATA:	Age: 45, Married, 4 children (Susan 18, Annette 16, Kevin 14, Natalie, 4)
EDUCATION:	BSEE - Brigham Young University, 1959 MSEE - University of Utah, 1962 Special Courses: Digital Communications RCA Institutes, 1967 Underwater Acoustics Bolt Berenek, Newman, 1966-67 Underwater Acoustics UCLA, 1966 Computer Programming Fleet Computer School San Diego, 1965
EXPERIENCE: BYU 1967-Present	Associate Professor Electronics Technology--Program Supervisor for the two and four-year programs in Electronics Technology. Supervises the development of the real-time control laboratory at BYU. Presently teaches courses in the Technology Department. Presently teaches courses in real-time computer systems, mini-computer process control applications, digital circuits, and logic design. Has taught courses in semiconductor electronics, instrumentation, trouble shooting, and AC and DC circuits. Directs the activities of the five faculty members who make up the Electronics Technology staff.
Systems Consultants, Inc. China Lake, CA Summer 1979 and Ridgecrest Engineering Co. China Lake, CA Summer 1980	Consulting Specialist. Accepted another assignment for planning an AGE Integration facility for NWC. Complete system layout was proposed and the major hardware interface between the integration facility Host Computer and the CP-3 aircraft computer was designed and completed. Other needed hardware was also designed, built, and documented. These systems were referred to as: (A) SEL 32/75 - CP-3 (Computer-to computer) Bus Oriented Interface (B) Analog - Dital Simulator Interface (C) Computer Control Unit Keyboard Simulator Interface Each interface functioned as designed and documentation was prepared for each of these design projects.
McKay Institute at BYU Spring 1978 to Fall	Designer: Designed and packaged a 16 channel student response system for classroom use, referred to as ECHO, for the McKay Institute at BYU. The system includes a digital interface between a PET microcomputer (which processes and stores the response data) and the student response keyboards.

Autonetics Div. of NAR Anaheim, CA Summer 1969	Member of technical staff. Wrote test specifications and program specification documents for design and check out of an F-111D aircraft real-time hybrid simulator.
Naval Underseas Center San Diego 1962-1964 1965-1967	Electronics Engineer (Electro Acoustics). In charge of an acoustic telemetering feasibility study. A digital transmitter was designed, receiving equipment and demodulation gear assembled, and several days of sea tests were accomplished. Data was processed and analyzed to determine the performance of digital acoustic telemetering. Also determined computer requirements for the DOLPHIN research submarine. Assisted in design of a deep ocean transducer calibration facility. Design circuits for transducer amplifiers, sonar display sweep circuits.
Montek Salt Lake City 1964-1965	Electronic Engineer (Design). Designed Digital and RF Circuits for TACAN aircraft beacon test equipment.
Univ. of Utah Salt Lake City 1961-1962	Teaching Assistant (½ time). Taught lab classes each quarter and taught one lecture course in basic E.E.
Sperry Utah Co. Salt Lake City 1959-1961	Engineer--Worked with a Ground Telemetry Receiving Station. Designed digital switching circuit. Designed and followed through production of a 50 Watt DC-DC Converter Voltage Regulator-power supply. (35 units). Company liaison with co-contractor on telemetry contract.

SPECIAL INTERESTS:

Computer Systems and Periferals--Hardware and/or software development for interfacing on-line, real-time computers for data acquisition and monitoring, testing, or process control applications.
Digital Communications and Telemetry--Logic circuit design, signal processing, encoding, or detection.
Underwater Acoustics--Applications of computers or other hardware to transmission, detection, or processing of acoustic signals.
Digital Circuits and Logic Design--Design of digital and logic circuits for any number of system applications.

PAUL R. SMITH

175 South 600 East #1
Provo, Utah 84601
(801) 377-8068

CAREER OBJECTIVE: Manufacturing Engineer using skills in development and implementation of Computer-Aided Manufacturing Systems.

EDUCATION: Bachelor of Science, December 1979, Brigham Young University, Provo, Utah

Major: Manufacturing Technology

Special emphasis in Computer-Aided Manufacturing Systems and Applications.

EXPERIENCE: December 1979 - Present. Research Assistant, BYU Computer-Aided Manufacturing Laboratory

1. Development and testing of hierarchical classification and decision-making trees for CAM applications.
2. Technical training to users of the DCLASS Information System.
3. Graduate course instructor in Group Technology.
4. Principal investigator for CAM-I Projects LA-81-PPP-01 and LA-81-PPP-03 on development for Process Planning Logic for XPS-1.
5. Project Manager for development of BYU CAM Mini-Lab.

January 1978 - December 1979. BYU Computer-Aided Manufacturing Laboratory

Special Projects -

1. Transportable Data Base development and testing using the DCLASS Information System.
2. Boeing Commercial Airplane Co. project involving the classification and coding of capital equipment.
3. CAM-I, INC. project involving the development and structure of OPCODES and Work Elements.

PERSONAL:	Age - 27 Married, two children Health - excellent	Height - 5'11" Weight - 200 lbs.
INTERESTS:	Firearms, wood and metal working, agriculture, photography, and music	
REFERENCES:	Dr. Dell K. Allen, Professor Manufacturing Technology Brigham Young University 195 South Inglewood Drive Orem, Utah 84057 (801) 225-3735	
	John J. Kunzler, Department Chairman Manufacturing Technology Brigham Young University 1909 South Main Orem, Utah 84057 (801) 225-8534	

APPENDIX C

UNSOLICITED PROPOSAL

6 Nov. 1981

- Unsolicited Proposal -

MANUFACTURING INFORMATION SYSTEM

Submitted to

Air Force Office of Scientific Research
Building 410, Room 223
Bolling Air Force Base
Washington, D.C. 20332 N.C.

Nov. 6, 1981

Principal Investigators:
D.K. Allen, P.R. Smith, & M.J. Smart

Computer Aided Manufacturing Laboratory
Brigham Young University
Provo, Utah 84602

AD-A137 891 MANUFACTURING INFORMATION SYSTEM(U) BRIGHAM YOUNG UNIV PROVO UT COMPUTER AIDED MFG LAB D K ALLEN ET AL. 22 DEC 83 AFOSR-TR-84-0031 AFOSR-82-0253 2/2

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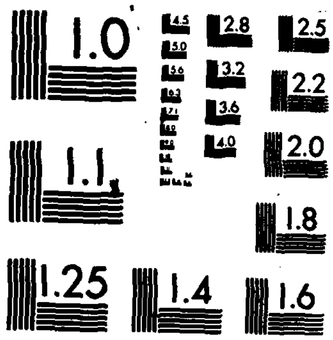


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

-ABSTRACT-

The size and cost of manufacturing equipment has made it extremely difficult to perform realistic modeling and simulation of the manufacturing process in university research laboratories. Likewise the size and cost factors, coupled with many uncontrolled variables of the production situation has even made it difficult to perform adequate manufacturing research in the industrial setting. Only the largest companies can afford manufacturing research laboratories; research results are often held proprietary and seldom find their way into the university classroom to aid in education and training of new manufacturing engineers.

It is the purpose for this unsolicited proposal to obtain a grant to continue the development of miniature prototype equipment suitable for use in an integrated CAD/CAM Laboratory. The equipment will be capable of actually performing production operations (e.g. drilling, milling, turning, punching, etc.) on metallic and non-metallic workpieces.

The integrated CAD/CAM Mini-Lab will integrate high resolution, computer graphics, parametric design, parametric N/C parts programmings, CNC machine control, automated storage and retrieval, with robotics materials handling.

The availability of miniature CAD/CAM laboratory equipment will provide the basis for intensive laboratory research on manufacturing information systems.

The proprosed research and development effort for the CAD/CAM Mini-Lab will be performed in three distinct phases. The <u>first phase</u>, lasting 2-years, will be devoted to prototype development and testing of the following miniature equipment (1) CNC Lathe, (2) CNC Mill, (3) CNC Turret Punch, (4) Storage and Retrieval System, (5) Micro-Robot, and (6) CNC Machine-Tool Control System. Demonstration software will also be developed for

integrating CAD/CAM graphics with the CNC Machine-Tool Control System. Phase two, one year, will be used for developing production models from the prototypes created during phase one, producing multiple copies of each piece of equipment and placing this equipment in a consortium of selected educational institutions. The planned phase three would be a one-year effort to develop extensive CAD/CAM software at institutions selected during phase two, concluding with a software exchange program. Software documentation standards would be provided for each institution to insure useability, transportability, and maintainability. It is expected that a vast amount of relevant manufacturing information will be collected and procedures developed from CAD/CAM Mini-Lab which will be directly applicable to a full-sized manufacturing plant operation. It is anticipated that programs developed by the educational consortium will include expansion of parametric design and programming applications, testing and evaluation of process control algorithms, evaluation and testing of programming procedures, experimentation with CAD/CAM Data Base design, development and utilization of group technology principles, shop floor scheduling and control, communication and distributed processing, etc., etc.

MANUFACTURING INFORMATION SYSTEM

1. INTRODUCTION

1.1. BACKGROUND In tracing the history of machine tools, it is interesting to note that machine-tools have developed over the past 200 years from relatively small mechanical devices with manual control to large, complex systems often containing electrical, electronic, hydraulic, and mechanical actuating and control subsystems.

The need for increased machine-tool complexity has arisen from increased sophistication of the products being designed and manufactured. Today, many consumer and user products contain electronic and microprocessor sinsing and control systems. Transportation and weapons systems contain the ultimate in complex configurations which must be designed, produced, and tested.

The size, complexity and cost of modern manufacturing equipment and systems is conderable; this has made it extremely difficult for universities to acquire modern manufacturing equipment for either education or for manufacturing research. Manufacturing research is essential in order to develop realistic process modeling and simulation studies. Education is essential if graduating engineers and technologists are to be aware of the principles governing optimum utilization of advanced manufacturing systems.

The size and cost factors of manufacturing systems, with many uncontrolled variables in the production situation has even made it difficult to perform adequate manufacturing research in the industrial setting. Only the largest companies can usually afford manufacturing research laboratories; research results are often held proprietary and seldom find their way into the university classroom to aid in the education and training of new manufacturing engineers.

1.2. NEED There is a current and pressing need to develop scaled-down and somewhat less sophisticated and less costly manufacturing equipment and systems for university level teaching and research purposes. The equipment must be capable of performing small-scale production operations and must be capable of being integrated into a system so that such things as data bases, data flows, control and scheduling, cutting forces, tool life, etc., may be realistically studied.

Once the hardware need is met then the next need is to model, simulate and test the manufacturing system. Modeling of an actual system can greatly facilitate testing of the computer simulation models. In many of the manufacturing simulation studies being carried out today, it is difficult to test the simulation model to insure its validity. The CAD/CAM Mini-Lab would solve this problem.

1.3. MISSION AND GOALS The mission of the manufacturing information system is to develop and test scaled-down manufacturing equipment and systems as a basis for manufacturing education, manufacturing research, and manufacturing simulation studies. Goals for accomplishing the stated mission include the following:

Goal 1. Design and develop prototype production equipment for processing and handling of box-like, sheet, and rotational parts made from metallic and non-metallic materials.

Goal 2. Design and develop a small, microprocessor-based, computer numerical control (CNC) system for controlling processing and handling equipment.

Goal 3. Develop and test the CAD/CAM interface between a small computer graphics display device and the CNC processing and handling system.

Goal 4. Develop production versions of the prototype hardware and produce a number of units for installation at selected universities who

are interested and capable of testing the equipment in the education and research modes. Every effort will be employed to create modular machine components to reduce production and maintenance costs.

Goal 5. Develop specifications and documentation guidelines for demonstration and research software for manufacturing information system studies based on CAD/CAM Mini-Lab equipment.

Goal 6. Develop and test CAD/CAM demonstration and research software at various university sites.

Goal 7. Establish a CAD/CAM Mini-Lab software exchange program for sharing programs developed for the CAD/CAM Mini-Lab.

Goal 8. Explore transferability of principles, concepts, and software designs from the CAD/CAM Mini-Lab environment to full-sized CAD/CAM systems operating in a real-world production environment.

During Phase I of the proposed grant program, only goals 1-3 will be addressed. Individual tasks for accomplishing each of the three stated goals are contained in Paragraph 1.4. Similar tasks will be developed for each of the other defined goals to insure that they can be met within the stated time and budget constraints.

1.4. METHOD OF PROCEDURE The method of procedure for this program has pretty well been established by preliminary R & D efforts funded by the CAM Laboratory at Brigham Young University.

This procedure has included accomplishing the following tasks:

1. Review existing full-sized CAD/CAM equipment and systems.
2. Develop an overall architecture for this CAD/CAM Mini-Lab including major hardware components.
3. Create high-level specifications for CAD/CAM hardware and software components.

4. Develop hardware mockups.
5. Develop detailed assembly and component drawings for each piece of equipment to be fabricated.
6. Fabricate, assemble and test equipment.
7. Design, code and test software.
8. Develop electronic interface between CAD and CAM hardware components.

A miniature Japanese camera lathe has been retrofitted with ball-screws and stepper motors. This CNC lathe is controlled by the MacSym computer for generating N/C cutter paths. Various families of parts can now be provided from data transmitted from the graphics system. No paper work is involved. All data is transmitted directly. A fiber-optic RS-232 link has been used for communication between the host computer and the lathe stepper motor driver logic.

A small EDM electrode drilling machine has also been retrofitted with ball-screws to provide a prototype for a 3-axis milling machine. This machine has also been equipped with a special table for circuit-board drilling.

A small 5-axis Microbot has also been acquired for the CAD/CAM Mini-Lab. This robot is commercially available, but has a number of failings and these include inability to accurately return to a home-position, and general lack of rigidity. The system is currently operated with a TRS-80 microcomputer.

1.5 ACCOMPLISHMENTS TO DATE Tasks No. 1 - 4 have already been completed as shown in the attached photograph (Attachment A). Task 5 is currently underway and detailed drawings have been completed for two of the six anticipated miniature machine tools (automated storage and retrieval system, and turret punch) and a miniature 5-axis robot is now being designed. Task 6 has been essentially completed for the miniature 8-station turret

punch.

A special stepper-motor driver card has also been developed for use with the Apple II computer numerical control (CNC) System and is now being tested.

Preliminary work has been accomplished in successfully connecting a Tektronix 4051 computer graphics system to a Macsym process control microcomputer which will act as the host for the Apple II/CNC machine controllers. Parametric design and part programming routines have been written and tested.

1.6 PLANS Plans for the near future include continuation towards the mission, goals and tasks stated earlier. Additional finding will accelerate progress and will permit: (1) upgrading of the Tektronix graphics system to the 4052 which is approximately ten times faster and which has improved graphics routines, (2) exploring the possibility of utilizing new Winchester disc technology with the Tektronix 4052, (3) utilizing the Corvus 10-MB Winchester disc as a shared device for the Apple II/CNC controllers, and (4) exploring the possibility of utilizing a lower cost Macsym 2 controller as the interface (host) computer, between the Tektronix 4052 and Apple II/CNC controllers. Alternately, we will be exploring the possibility of using another Apple II Computer as the Host for scheduling purposes. (This latter option will require writing or acquiring a real-time operating system for the Apple II.)

2. IMPACT ON MANUFACTURING SCIENCE AND TECHNOLOGY

2.1 ANTICIPATED RESULTS While the full-sized CAD/CAM laboratories at Brigham Young University have attracted considerable attention the most impressive thing to many visitors has been our work with the CAD/CAM Mini-Laboratory. Already two theses have been completed using the Mini-Lab by students who are enrolled in the M.S. Degree Program in Computer Aided

Manufacturing; and three additional theses are in progress.

In view of the enthusiastic response we have had from visitors who have seen our CAD/CAM Mini-Lab and very positive response we have had with graduate research projects we believe the proposed project can have a rapid, and far-reaching impact on improving manufacturing technology and developing a manufacturing science. One other project which is currently underway at the university and which can have a synergistic effect with the CAD/CAM Mini-Lab is the development of manufacturing training materials. The project, funded by an industrial consortium, is developing some 250 educational modules for conventional and advanced production processes. The project is expected to last 42-months and cost $1.2 million dollars. Deliverables will include transparency masters, student handouts, 35mm slides, video-tapes, and eventually an interactive videodisc delivery system. By vote of the consortium members, we will branch out to include CAD/CAM activities as soon as the planned modules are completed.

There is a natural interaction between the training materials described above and the CAD/CAM Mini-Lab discussed in this proposal.

2.2 SUPPORT FOR AGENCY It is our belief that successful completion of the two projects just described plus our own demonstrated and successful completion of generative process planning using DCLASS, can have greater impact on manufacturing science and technology than any other combined activity.

The stated mission of the CAM Laboratory is "to aid in increasing industrial productivity through the application of advanced technology". Participation by the Air Force Office of Scientific Research can aid in accelerating the development work and in dissemination to qualified educators and researchers.

One of the five major program areas identified by the Air Force Office of Scientific Research is that of Manufacturing Science. Like any science Manufacturing Science must be based upon theory, observation, experimentation, modeling, simulation, etc. The proposed project directly supports the Manufacturing Science program by making available suitable equipment for laboratory research.

3. UNIQUENESS OF PROPOSAL The AFOSR is probably in the best position to judge the uniqueness of this proposal. We know of no other investigators who have such a comprehensive plan unless they have received it from us. We are aware of projects which use Erector-set equipment for simulation of transfer line machining, and peg-board type storage and retrieval systems; we are also aware of work that has been done with miniature computer controlled milling machines, and in fact some are commercially available at nearly the cost of full-sized equipment, but we have yet to see any work relative to an integrated miniature CAD/CAM System which can actually produce parts.

4. QUALIFICATIONS OF PERSONNEL All personnel selected for this project have already been involved and have demonstrated their proficiency. Resumes are attached.

Briefly, qualifications and duties are as follows:

Principal Investigators:

1. D. K. Allen, Director of CAM Laboratory, Professor of Manufacturing Technology, Originator of concept for CAD/CAM Mini-Lab.
2. P. R. Smith, Research Associate, CAD/CAM Mini-Lab project manager, teaches course in Group Technology, has been involved with Educational Module Development Project.
3. M. J. Smart, Associate Professor of Electronics, Teacher

course work in Computer Technology, broad industrial experience; has been involved with assembly language programming of CY 512 for process control.

Technician/Design Consultant:

1. V. L. Dearden, Prototype Development Technician, extensive industrial experience, tool-die and prototype development.
2. F. Blair, Mechanical Designer, Inventor, Technical Illustrator.

5. FACILITIES AVAILABLE There are presently some 19 machine shops and electronic shops on the BYU campus including a large research shop. Equipment is available for conventional and CNC production. Modern laboratory facilities are also available for sheetmetal forming, plastic molding, casting, welding, finishing, painting, heat-treating, and inspection.

6. COST OF SPECIAL EQUIPMENT Following is a list of special equipment which will be required for design and testing of the prototype production system.

		TOTAL
5 ea	Apple II 40-K Microcomputers @ $1075 ea	5,375
6 ea	15 ft Cable and Interface Card @ $205 ea	1,230
1 ea	Corvus 10-MB Winchester Disc	4,370
1 ea	Host Multiplexer for Corvus Disc	735
1 ea	Mirror Backup/Recorder	840
1 ea	Tektronix 4052 graphic display	10,950
	with option 24, 64K Bytes memory	2,000
	with option 01 Data Communication Interface	1,500
	TOTAL	$27,000

Equipment which is already on-hand and being used currently for the Mini-Lab includes: 1-Apple II/Display Micro Computer, 1-Macsym II Micro-Computer, 1-Tektronix 4051 (early version to be upgraded), 1-TRS-80 (Radio

Shack) Micro Computer, 1-Microbot-5 Miniature Robot, 1-Toyo Camera Making Lathe, 1-Horizontal Drilling/Milling Machine.

The special equipment acquired with this grant will be used solely for the implementation of the prototype CAD/CAM Mini-Lab project. At the completion of the project, title to equipment used for prototype development will be conveyed to Brigham Young University.

7. TIME SCHEDULE

7.1. TOTAL DEVELOPMENT TIME The time schedule for the three development phases is as follows: Phase I, prototype development (this p[illegible]posal) 24-months; Phase II, prototype production, software specificati[illegible] and institution selection, 12-months; Phase III, software development a[illegible] [illegible]tware exchange, 12-months. Total development time: 48 months.

7.2 TIME SCHEDULE, PHASE I The time schedule for Phase I of the project is 24-months. A detail of the tasks to be completed is shown on Figure 1.

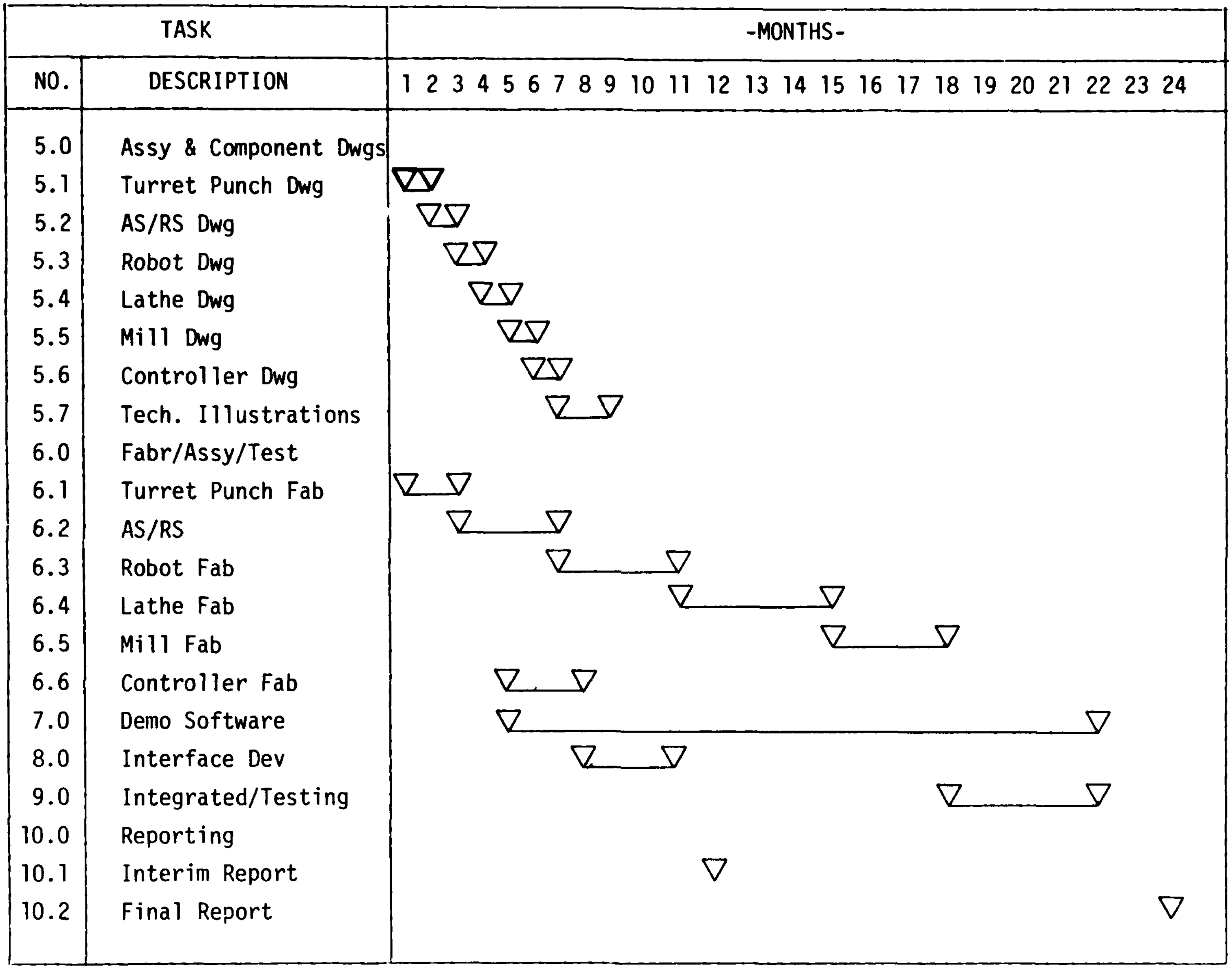
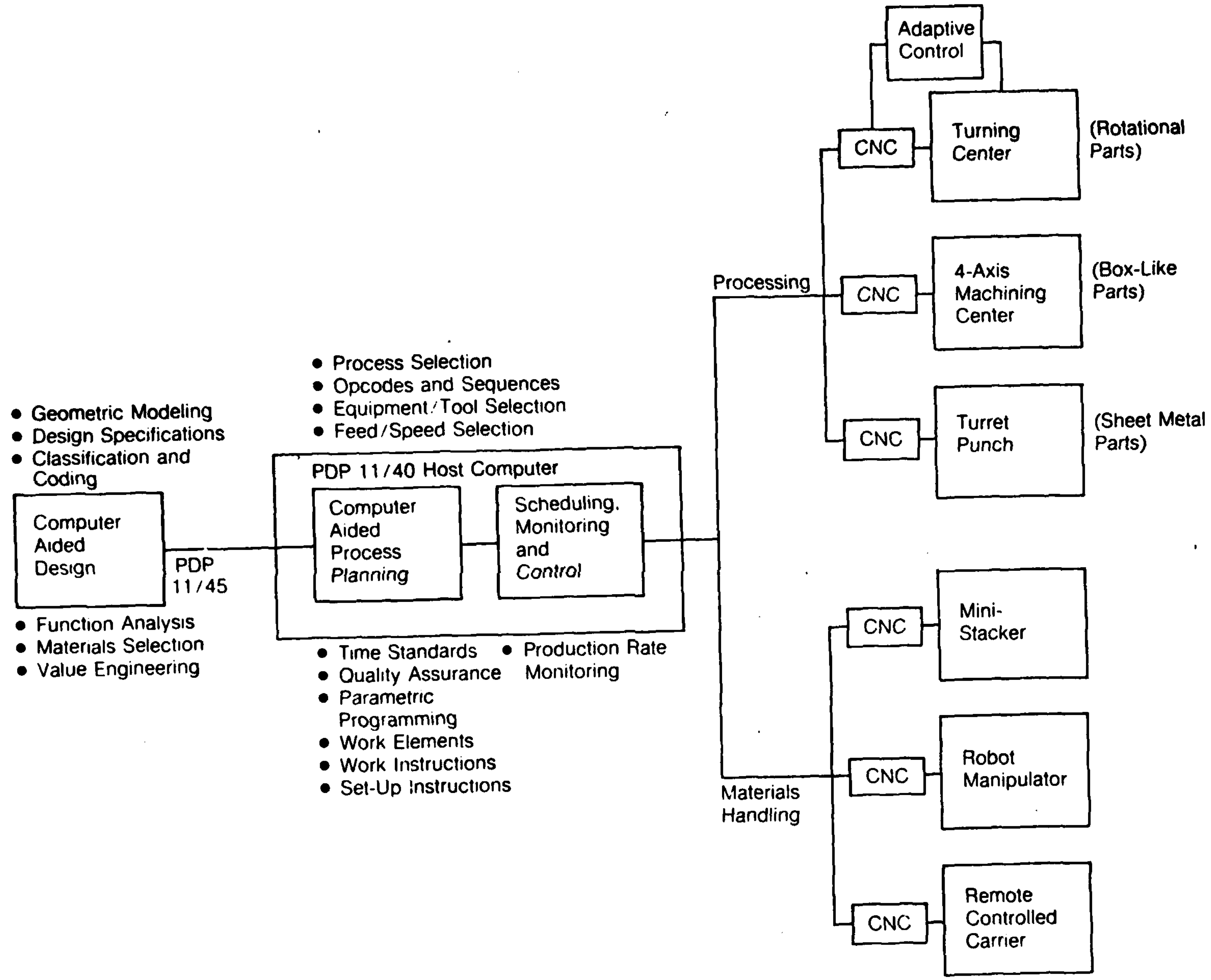

TASK
-MONTHS-
NO.
DESCRIPTION
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
5.0 Assy & Component Dwgs
5.1 Turret Punch Dwg
5.2 AS/RS Dwg
5.3 Robot Dwg
5.4 Lathe Dwg
5.5 Mill Dwg
5.6 Controller Dwg
5.7 Tech. Illustrations
6.0 Fabr/Assy/Test
6.1 Turret Punch Fab
6.2 AS/RS
6.3 Robot Fab
6.4 Lathe Fab
6.5 Mill Fab
6.6 Controller Fab
7.0 Demo Software
8.0 Interface Dev
9.0 Integrated/Testing
10.0 Reporting
10.1 Interim Report
10.2 Final Report

Figure 1



• Geometric Modeling
• Design Specifications
• Classification and Coding
Computer Aided Design
• Function Analysis
• Materials Selection
• Value Engineering
PDP 11/45
• Process Selection
• Opcodes and Sequences
• Equipment/Tool Selection
• Feed/Speed Selection
PDP 11/40 Host Computer
Computer Aided Process Planning
Scheduling, Monitoring and Control
• Time Standards
• Quality Assurance
• Parametric Programming
• Work Elements
• Work Instructions
• Set-Up Instructions
• Production Rate Monitoring
Processing
Materials Handling
Adaptive Control
CNC
Turning Center
(Rotational Parts)
CNC
4-Axis Machining Center
(Box-Like Parts)
CNC
Turret Punch
(Sheet Metal Parts)
CNC
Mini-Stacker
CNC
Robot Manipulator
CNC
Remote Controlled Carrier

APPENDIX D

CAM MINI-LAB CONCEPT

Enclosure From Memorandum
From D.K. Allen to J.J. Kunzler

Dated 22 May 1979, Re: "Windfall Money"

COMPUTER AIDED MANUFACTURING MINI-LAB

Enclosure to Memorandum

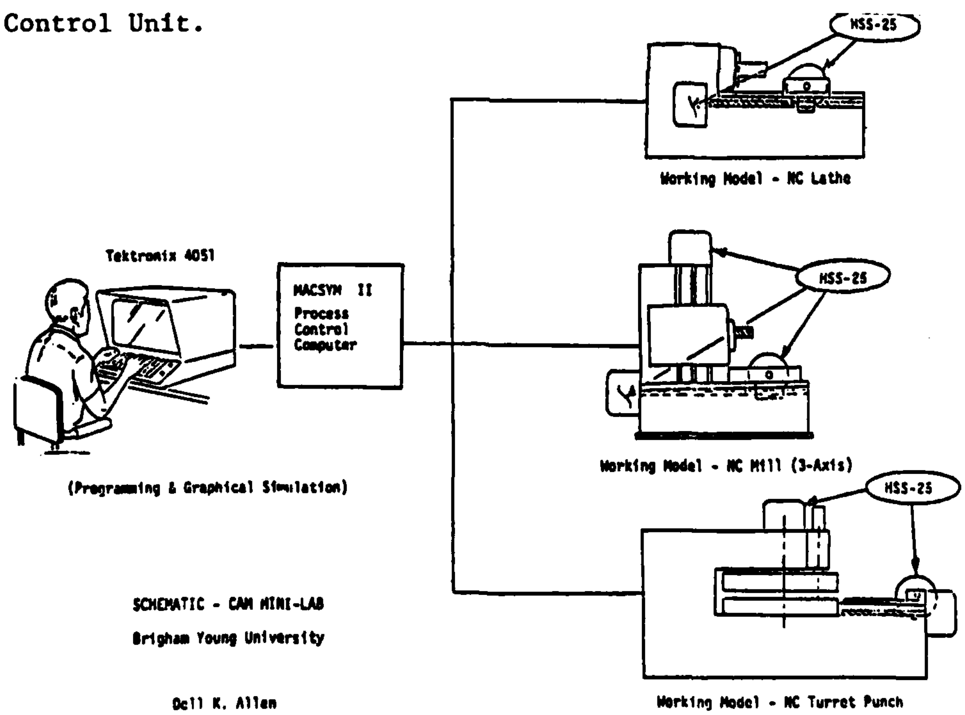
From D.K. Allen to J.J. Kunzler
Dated May 22, 1979

Re: Windfall Money

COMPUTER-AIDED MANUFACTURING MINI-LAB

In addition to the full-size demonstration equipment used in the Computer-Aided Manufacturing Laboratory at BYU, a CAM Mini-Lab is also being developed. The purpose for the Mini-Lab is to give the students an introductory experience in programming, scheduling, modeling, simulation, and process sensing and control prior to actually performing research and prototype production on full-size equipment. The Mini-Lab will also provide an excellent opportunity to give a short course to non-majors, managers, and others in a non-threatening environment without fear of damage to personnel or equipment.

The scale model machines used in the Mini-Lab are shown in the figure below along with the Tektronix 4051 Micro-Computer Graphics Terminal and the CNC Control Unit.



The machines will be modular in design and will be produced from aluminum castings. They will be equipped with steel ways, ball screws, small, high-speed digital stepping motors, and permanent magnet drive motors. The machines

will actually be capable of machining soft materials such as styrofoam, wood, etc.

In operation, students will be able to develop part programs for machining various configurations, graphically verify the cutter-path, and then schedule the production. Parametric part programming will be stressed based upon principles of Group Technology. Machining economics, and metal cutting parameters will be established through the use of various computer program modules and function keys.

In terms of process sensing and control, the students will be able to access either a machine monitor unit, or actual process sensors attached to the lathe. Spindle speed, feed rate, force temperatures, and acoustic signals will be accessed. From these signals, a response surface will be developed as a preliminary step in developing an adaptive control system.

The CAM Mini-Lab will provide a flexible, low-cost, and easy to use facility for introducing students to basic concepts of Computer-Aided Manufacturing.

APPENDIX E

CAD/CAM MINI-LAB '81

PRESENTATION BY INDUSTRIAL DESIGN STUDENTS
TO BUSINESS AND INDUSTRY REPRESENTATIVES

22 June 1981

CAD/CAM MINI-LAB '81

Industrial Design Department
Brigham Young University

Presentation

June 22, 1981
357 ELWC
10:30 AM

BACKGROUND:

The Computer-Aided Manufacturing (CAM) Laboratory in cooperation with the Industrial Design Department is developing a new line of miniature laboratory equipment for use in CAD/CAM education and training programs.

The concept for the CAM Mini-Lab was developed by Dr. Dell K. Allen in 1975-76 after seeing a small computer controlled material handling device in use at the Caterpillar Tractor Facility.

Mr. Charlie Snead, Graduate Student, (now with Westinghouse) put in place the first phase of the prototype system at BYU when he successfully interfaced the Tektronix 4051 to the MACSYM 2 Computer for controlling a miniature metal cutting lathe.

Mr. Paul Smith, full-time Research Associate, is now responsible for the development and integration of the new CAD/CAM Laboratory incorporating a whole spectrum of equipment.

Industrial Design students under the direction of Professor W. Douglas Stout have focused on the needs of the CAD/CAM Mini-Lab and here present their proposed designs and mockup models.

CAD/CAM MINI-LAB '81

Introductory Remarks. . . . . . . Dell K. Allen, Director
Computer-Aided Manufacturing Laboratory

Industrial Design Process . . . . Professor W. Douglas Stout
Chairman
Industrial Design Department

PRESENTATIONS: (10:30 AM - 12:00 Noon)

1. "Computer Numerical Control Unit"
   Alan Hansen

2. "Automated Storage and Retrieval System"
   Russel Richins
   Mike Carroll
   Kevin Olson

3. "Industrial Micro-Robot"
   Garn Israel
   Janet Pace
   Eric Simpson

4. "CNC Lathe"
   Tjoen Lie
   Alan Breese

5. "CNC Milling Machine"
   Marty Watts
   Leslie King
   Bill Davis

6. "CNC Turret Punch (Laser Router)"
   John Fossom
   Keith Poulson

12:00 PM - 12:30 PM - Light/Heavy Refreshments

END

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DTIC